Heat Transfer Characteristics Analysis of Single Turn Closed Loop Pulsating Heat Pipe

Rudresha S[1], Ayush Kumar Singh[2], Abhinav yadav[3], Deepak Kumar Maddeshiya[4], Anuj Singh[5]

[1]Assistant Professor, JSS Academy of Technical Education Noida, Uttar Pradesh, India
[2,3,4,5]Student, Department of Mechanical Engineering, JSS Academy of Technical Education Noida, Uttar Pradesh, India

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Abstract - *A Pulsating heat pipes (PHPs) are passive heat Transfer devices with a considerably greater heat transfer rate than traditional heat transfer devices like metal fins. The oscillating motion of the bubbles inside PHPs causes a two-phase phenomenon. The Pulsating Heat Pipe (PHP) is a type of heat exchanger that collects heat from the evaporator and transmits it to the condenser. A multi-phase flow occurs in a pipe. Capillary action causes vapor plugs and liquid slugs to develop in PHP. Water and Methyl Alcohol are utilized as working fluids in CFD modeling in ANSYS fluent with a single turn of PHP. The CFD results obtained are compared. The simulation outputs are presented in graphs and contours, and the CFD analysis is completed. The flow pattern of the fluid inside the PHP is reflected by changes in volume fractions of water-air and Methyl Alcohol-air in three regions: evaporator, adiabatic region, and condenser. The analysis uses a typical K-epsilon model for the improved wall treatment to analyze the thermal impacts of fluid on the curvature of a single turn closed-loop pulsating heat pipe at various times.*

***Key Words*: Two-Phase Flow, Pulsating Heat Pipes (PHP), Working Fluids, Computational Fluid Dynamics (CFD), Closed-loop systems, CLPHP.**

1.INTRODUCTION

Heat pipe technology was developed in the early 1960s and has since evolved into many other shapes and forms. It has also been used in several applications, including cooking, fuel cell cooling, and space heating and cooling, spanning from computer cooling to spacecraft thermal management. Depending on the use, heat pipes come in a variety of shapes, sizes, and combinations.

The slug/plug motion of the working fluid in the tube, which is generated by evaporation, is the driving force of a pulsing heat pipe (PHP). PHPs are formed from a twisted tube with several parallel channels. It may be configured as an open or closed loop. The PHP has a vacuum and charge service valve on one end, which is pinched off and welded into the first (this valve can be later removed). The closed-loop PHP is an endless tube since both ends are welded together. Each PHP installation has its unique running modes, which are primarily determined by the slug/plug motion. Both PHP designs are extremely reliant on their thermal behavior with the gravity vector during operation, which must be carefully evaluated. The PHP reaches higher temperatures when running in a vertical position, but lower temperatures when operating in a horizontal configuration.

Closed-loop Pulsating heat pipes (CLPHPs) are made up of a simple meandering tube with several U-turns and are linked end to end for microelectronics cooling. The pipe is first emptied, then partially filled with a working fluid. The fluid distributes itself into an arrangement of liquid slugs separated by vapor bubbles if the diameters of the closed-loop pulsing heat pipe are not too big. A pulsing motion of the liquid-vapor/slug-bubble system receives heat at one end of this tube bundle and transfers it to the other end. The thermally produced pressure pulsations inside the device create the liquid and vapor slug/bubble movement, and no external mechanical power is required. The kind of fluid and operating pressure inside the pulsing heat pipe are determined by the heat pipe's operating temperature.

An adiabatic zone separates the evaporator from the condenser. Heat is transferred from the evaporator to the condenser by the pulsating movement of the vapor and liquid slugs. This pulsation looks to be a chaotic non-equilibrium activity whose continued operation demands non-equilibrium conditions in a few parallel channels within the tube. To start or maintain fluid motion or heat transfer, close loop pulsing heat pipes (CLPHPs) do not require an external power source. The objective of this study is to learn how CLPHPs work and how different factors (geometry, fill ratio, materials, working fluid, and so on) influence their performance. The non-equilibrium nature of the evaporation and condensation processes, bubble development and collapse, and the linked response of the multi-phase fluid dynamics among the multiple channels make understanding its functioning even more difficult.

1.1 Heat Pipe

A heat pipe is a self-heating device that transfers heat from one end (heat injection) to the other (destination) with minimal temperature variations while simultaneously passing heat over the interior surface. The evaporator and condenser are the two halves of the heat pipe. Between the condenser and the evaporator lies an adiabatic zone. The heat pipe consists of a wall, a wick structure, and a working fluid area.

The Heat pipe is similar to a liquid (2 phase) pumped loop in that the wick material performs the pumping operation.

1.2 Working principle of Heat Pipe

They are vacuum-sealed and filled with a predetermined amount of working fluid. The working fluid is first confined inside the wick-lined structure that lines the inside of the heat pipe. The fluid/water inside the heat pipe evaporates in vapor when an electronic component creates heat for input, which is known as the evaporator portion or bottom end. The water vapor spreads quickly and travels to the heat pipe's other end (condenser), utilizing the pressure created by the smallest temperature difference.

The working fluid/water rejects its latent heat at the other end, known as the condenser portion, which is rejected or produced by an external device, such as a heat sink.

The water then returns to a liquid/fluid state, and the wick structure inside the heat pipe uses capillary force to push the fluid/water in the opposite direction to the evaporator portion.

The heat transmission mechanism becomes highly fluid and efficient when these liquid and vapor phases are used. Heat pipes function constantly and passively due to their closed-loop design, becoming a dependable and passive component of your thermal management system.

2. OBJECTIVE

The goal of this project is to use ANSYS FLUENT to investigate the performance of a closed-loop pulsing heat pipe with a single turn. The thermal effects of fluid on the curvature of a Single turn Closed-loop Pulsating heat pipe are evaluated at various times using a conventional K-epsilon model for the improved wall treatment, and the findings produced by CFD analysis are compared.

3. METHODOLOGY

First, a literature review of the operation and performance of pulsating heat pipes is conducted (PHP). Various publications have been researched and analyzed in this respect to serve as a reference for fundamental geometry, operating conditions, and performance characteristics.

The simulation is then repeated until the tools for solving the model meet the necessary convergence requirements, allowing for precise and accurate analysis.

3.1 First Step

A review of the literature on the performance and operation of pulsing heat pipes is conducted. This material was used to create the current work, and different experimental papers were used as a reference for PHP's fundamental geometry.

ANSYS FLUENT is used to generate geometry. Meshing is done for the geometry, and meshing sections are given names to make it easier to define the domain and specify boundary conditions in FLUENT.

3.2 Second step

For the current analysis, several techniques and tools are selected in ANSYS FLUENT setup and FLUENT solution at this stage

3.2.1 ANASYS Setup

Transient analysis, multiphase models, volume fraction model, the effect of courant number on analysis, turbulence model, material and phase selection, boundary conditions like momentum and thermal properties, and cell conditions operating pressure, temperature, and fluid density are among the methods and tools selected in the ANSYS FLUENT setup.

This is a critical step in the CFD analysis.

3.3 Third step

The time step size and number of timesteps are specified in the run calculation, so the simulation continues until the convergence conditions are met. After completing the appropriate number of iterations of different phases of water and methyl alcohol, findings are received at this step.

3.4 Forth Step

After that, the findings of the CFD study of water and methyl alcohol are compared, and the influence on the curvature of pulsing heat is investigated.

4. CFD MODELING OF SINGLE LOOP PHP

4.1 CFD Procedure

ANSYS FLUENT software is used to do a 3-D study of fluid flow and heat transfer for the tube using the volume fraction technique. The evaporator, adiabatic section, and condenser portions make up the PHP.

The length of the evaporator region is 45 mm.

The length of the condenser region is 63 mm.

Adiabatic Region Length =178 mm

4.2 Geometry

Pulsating Heat Pipe is a closed kind that uses a single turn of a Copper tube with an inner diameter of 4mm and a thickness of 0.0001mm. The copper domain is not taken into account in the geometry modeling; only the fluid domain is taken into account. Figure 1 depicts the geometry that was constructed.

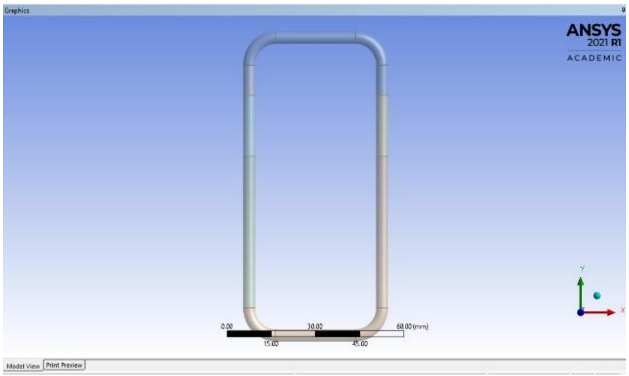

Chart -1: Geometry modeling of a single turn PHP

The reference of geometry design of closed-loop pulsing heat pipe (CLPHP) is taken into consideration in this current study for constructing geometry, as indicated in many research publications. The channel's overall length and diameter are mm and mm, respectively, and the pipe is composed of copper.

4.3 Meshing

ANSYS With the possibility to define combinations of point controls, edge controls, surface controls, and/or body controls, meshing adds even more control. Each of them has its own set of settings that may be used to alter the mesh in various ways. The automated approach for mesh form is chosen in this example, however, the mesh sizing is done manually.

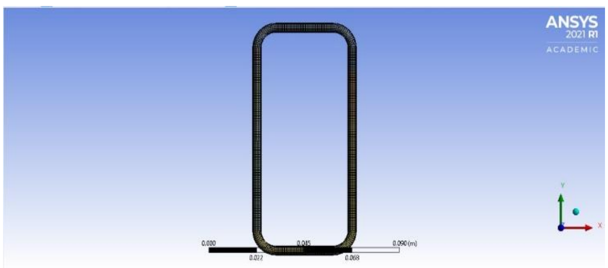

Chart -2: Shows the grid of a section of geometry.

4.4 Turbulence Model

The k-epsilon model, one of the most well-known turbulence models, was used in this research, as it is in most general-purpose CFD programs, and is considered the industry standard model. It has a well-established predictive capacity and has shown to be stable and numerically robust. The k-epsilon is a reasonable balance between accuracy and resilience for general-purpose simulations.

4.5 Governing Equations

4.5.1 Governing equations of vapor plugs

The continuity equation for the i^{th} vapor plug is

$$\frac{dm_{vi}}{dt} = \dot{m}_{in,vi} - \dot{m}_{out,vi} \quad (1)$$

Vapor Plug energy equation is given by

$$\frac{d(m_{vi}u_{vi})}{dt} =$$

$$\dot{m}_{in,vi} h_{vi} - \dot{m}_{out,vi} h_{vi} - p_{vi}\frac{dV_{vi}}{dt} \quad (2)$$

4.5.2 Governing equations of vapor plugs

The momentum equation for i^{th} liquid slug is

$$\frac{dm_{li}v_{li}}{dt} =$$

$$(p_{vi} - p_{v(i+1)})A - \pi d L_{li}\tau - \pi d\sigma - (-1)^n m_{li} g \quad (3)$$

4.5.3 Evaporation

Kim et al. (1999) found that the formation of bubbles in the evaporating section was a nucleate boiling process based on experimental data from flow imaging of the PHP. The heat transfer rate in nucleate boiling is quite high, yet there is currently no appropriate physical description of the thermodynamical process. The following is a generic statement given by Dario Delmastro and Alejandro Clause (1994) to connect the nucleate boiling regime:

$$q = C(p, fluid, surface)(T_w - T_{sat})^n \quad (4)$$

The recommended value for the exponent n is 3.

4.5.4 Condensation

In the cooling section, a theoretical model of film condensation is shown. The vapor velocity in the model is low in most portions of the cooling section because each vapor plug is surrounded by two liquid slugs. Furthermore, heat transmission in the thin liquid layer is considered to be solely due to radial conduction. Hence, the mean value of condensation heat transfer coefficient, h_{cond}, may be determined by the following expression (John, 1994)

$$h_{cond} = 0.943\left[\frac{\rho_f(\rho_f - \rho_g) g \sin\theta \, h_{fg} k_f^3}{\mu_f L_c (T_{vi} - T_w)}\right]^{\frac{1}{4}} \quad (5)$$

Where Θ is the inclination angle of the PHP.

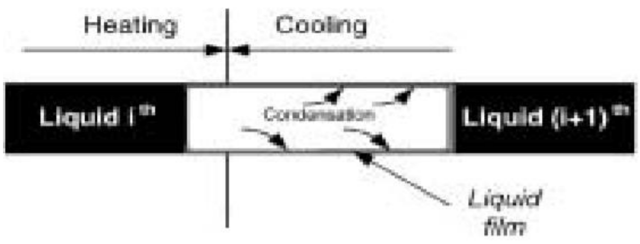

Chart -3: Control volume of ith vapor plug

4.5.5 Heat Transfer

The total heat transported from the heating to the cooling sections of the PHP is defined as the total heat transferred from the heating to the cooling sections owing to evaporation and condensation of the working fluid.

Each vapor plug's evaporation and condensation heat transfer may be computed using

$$Q_{in,vi} = \dot{m}_{in,vi} h_{fg} \quad (6a)$$

$$Q_{out,vi} = \dot{m}_{out,vi} h_{fg} \quad (6b)$$

The total transferred into and out of the PHP can be calculated by

$$Q_{total,in} = \sum_{i=1}^{N} Qin, vi \quad (7a)$$

$$Q_{total,out} = \sum_{i=1}^{N} Qout, vi \quad (7b)$$

5. RESULTS

5.1 Result of CFD Analysis of water

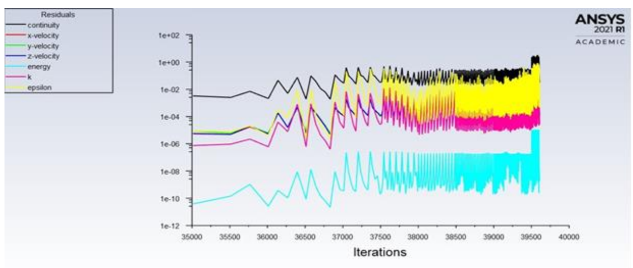

Chart -4: Volume fraction vs no. of iteration

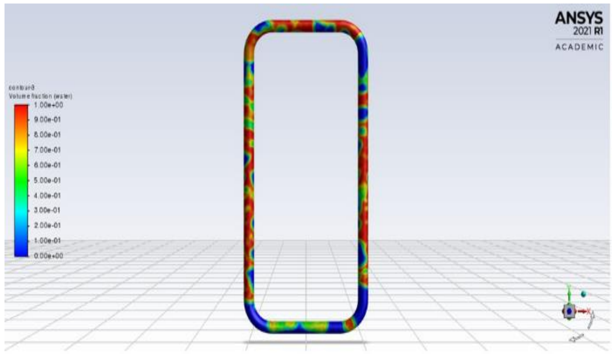

Chart -5: Contour of water

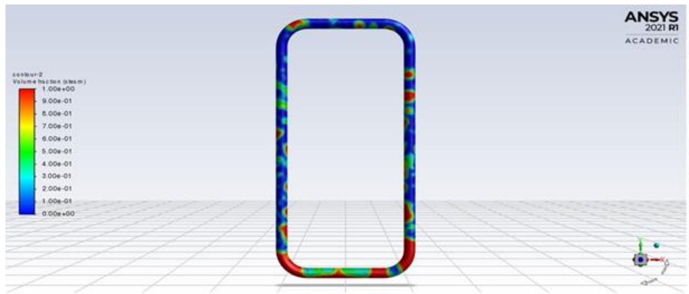

Chart -6: Contour of steam

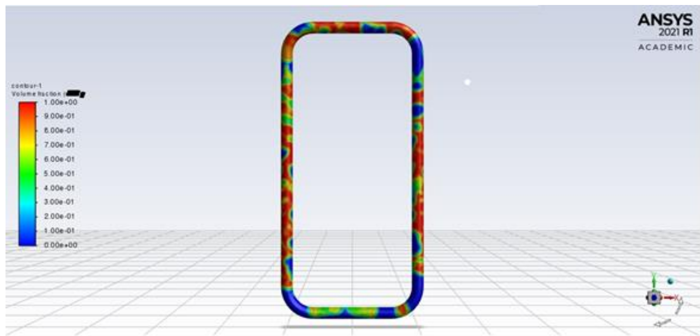

Chart -7: Contour of mixture

5.2 Result of CFD Analysis of Methyl Alcohol

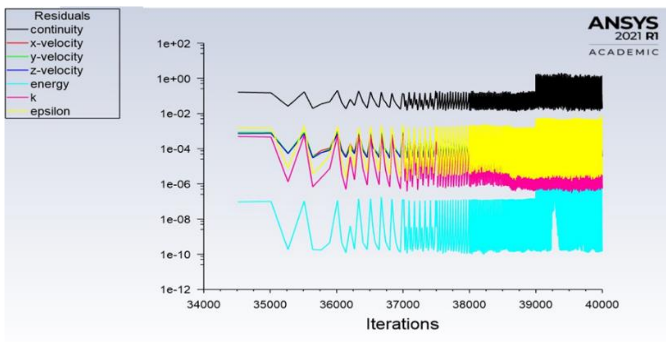

Chart -8: Volume fraction vs no. of iterations

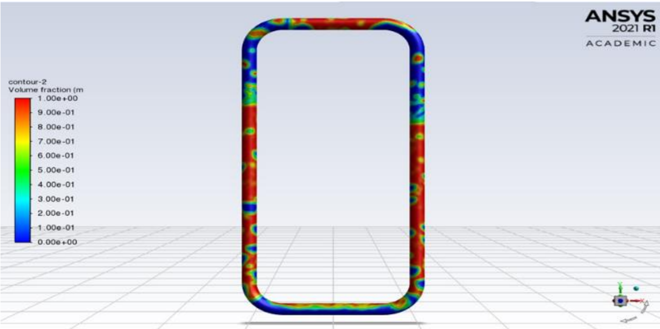

Chart -9: Contour of methyl alcohol vapor phase

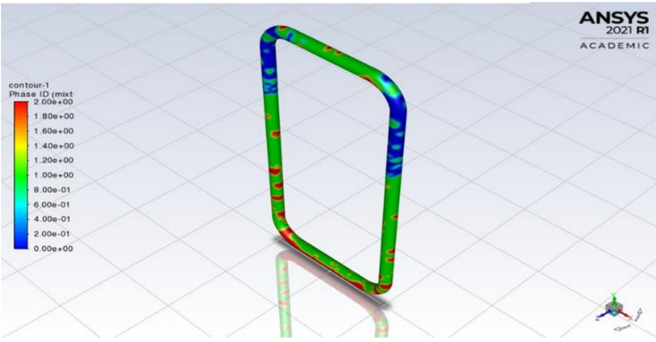

Chart -10: Contour of mixture

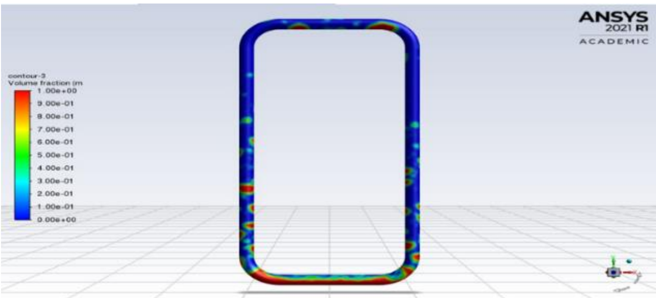

Chart -11: Contour of methyl alcohol liquid phase

6. CONCLUSIONS

To analyze the thermal performance of fluids concerning time, CFD analysis is done first with different phases of water and air AND then with different phases of methyl alcohol and air. The flow patterns in the analysis were observed for both water and methyl alcohol, using the volume of the fluid model to evaluate the phase transition process and the surface force model to assess the influence of surface tension.

In a single turn closed loop pulsing heat pipe with bubble formation and development motion seen in the evaporator section with vapor plugs oscillation and circular motion, the simulation using an antique model was effective. The system flow varies between several types of fluid slugs and plug structure forms during early operation, but after some time, the pattern stabilizes. The higher resolution allows us to see the internal operations and retrieval operation change in volume fraction of methyl alcohol and air AND water and air in three areas, viz. Evaporator, adiabatic, and condenser region reflects the flow pattern of fluid inside the pipe.

Describe the temperature of the fluid in the evaporator in the analysis shows that heat is transported to the condenser section, and it is seen that it is more apparent in methyl alcohol than in water, as the temperature begins to decrease at a quicker pace.

As a result, we infer that when various phases of fluids, such as water and methyl alcohol, are analyzed. Water has superior flow and heat transfer properties than methyl alcohol

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