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Design and Computational Fluid Dynamics Analysis of Heat Pipe in Ansys Fluent

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Abstract - *Heat pipes with broad applications in thermal systems can supply effective heat transport with minimal losses over reasonable distances. Heat pipes are promising means to drive the heat from the electronic device to the environment without using mechanical devices to operate the flow. The heat pipe is a thermodynamic device of very high thermal conductance. This study represents a Phase Change and CFD heat transfer analysis for heat pipe. The article deals with creating the premise of the CFD model of the heat pipe, which is meant to simulate and show the anticipated course of the work-fluid activity within the heat pipe. The optimization transferred to the CFD model will show us how to solve problems and enhance the experimental models of heat pipes.*

***Key Words*:** Heat Pipe, capillary pumped loops heat pipe (CPLHPs), Ansys, Finite Element Analysis,

1. INTRODUCTION

Heat pipes are used widely in broad applications since their operation is generally passive. High heat transfer rates are doable by heat pipes over long distances, with minimal temperature difference, exceptional flexibility, simple fabrication, and easy control, all without any external pumping power applied. Heat pipe development is motivated to overcome the need to manage thermal dissipation in progressively compressed presumably and higher-density microelectronic components. In recent years, many different types of heat pipes have been developed to address electronics thermal management problems, solar energy, and many other applications and are shown promising results. The type of fluid and the operating pressure inside the pulsating heat pipe depend on the operating temperature of the heat pipe. The region between evaporator and condenser is adiabatic. The heat is transferred from the evaporator to the condenser by pulsating the vapor slug and liquid slug. This pulsation appears as a non-¬ equilibrium chaotic process whose continuous operation requires non-equilibrium conditions inside the tube in parallel channels. For Close Loop Pulsating heat pipes (CLPHPs), no external power source is needed to initiate or sustain the fluid motion or heat transfer. The purpose of this project is to understand how CLPHPs operate and to be able to understand how various parameters (geometry, fill ratio, materials, working fluid, etc.) affect their performance.

1.1 Objectives of this Study

The goals of the present work are to employ and develop a robust numerical method to study the steady-state and transient performance of high heat flux heat pipes using as few assumptions as possible.

The two essential adjustments are:

1. The fundamental formulation of the heat pipe is developed in such a way to properly consider the change in the system pressure based on mass depletion\addition in the vapor core.
2. The numerical sensitivity of the solution procedure on phase change at the liquid-vapor interface is recognized and effectively handled by reformulating the mathematical equations governing the phase change.

2. Fundamentals of Heat Pipe

Heat pipe design and modeling demonstrate the increase in thermal performance. Heat pipes are passive two-phase heat transfer devices using liquid to vapor phase transition to provide minimum temperature rise across their length; a typical copper water heat pipe operates with a 2 to 5-degree temperature difference. During heat pipe operation, the fluid in the wick structure creates an internal pressure gradient; this pressure gradient moves the vapor to the cooler region known as the condenser for a transition back to liquid. The liquid then passively pumps back to the evaporator by a wick structure. This cycle is continuous if there is a temperature difference across the length of the heat pipe. The heat pipe almost instantaneously moves to heat when moved back to the cooler region to heat pipe again cool down at a much faster rate.

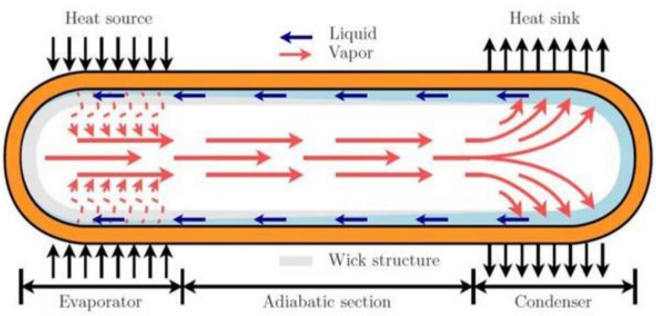

Figure 1. Fundamental of Heat Pipe

Heat pipes are lightweight, thin-wall tubes with a minimal amount of working fluid; therefore, their thermal properties also reduce the overall size of the heatsink or heat spreader. Our models can adjust the bulk thermal conductivity at the plate. The test results provided range mainly dependent on geometry as prominent form factors can achieve higher effective conductivity. Heat pipes provide a very long life when appropriately manufactured. 20+ years operation is routine for heat pipes operate in any environment: heat pipes themselves or thin wall tubing. However, they can withstand harsh environment requirements such as shock vibration and extreme temperatures when appropriately integrated. Copper water heat pipes are typical for terrestrial applications. The explanation of heat pipe operation in a cylindrical geometry is shown in Figure1. However, the shape and size of the heat pipes can be different. Heat pipes have consisted of a closed container (pipe wall and end caps), a wick region\structure, and working liquid in an equilibrium state with its vapor. Most used working fluid choices are water, acetone, methanol, ammonia, or sodium, depending on the operating temperature.

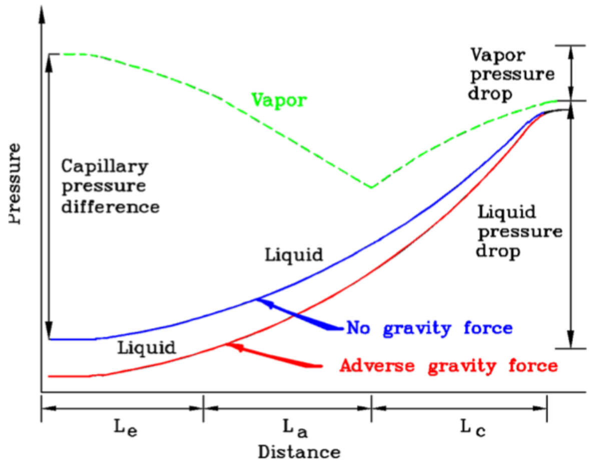

Figure 2. Graph of typical vapor and liquid pressure distribution inside a heat pipe

1. Heat Pipe Modeling

Assumptions and formulations play a very crucial role in heat pipe simulation. However, an authentic simulation of heat pipe takes much work and is almost impossible since the phenomenon in multi scales levels needs to be addressed.

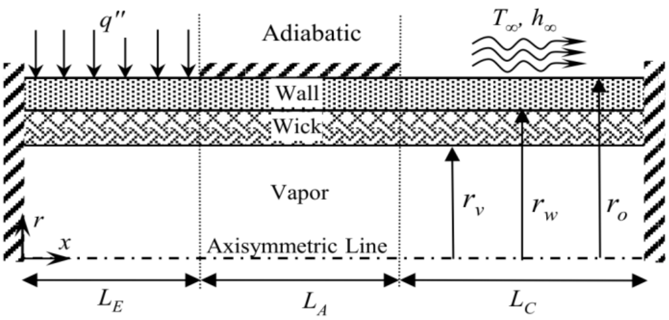

Figure 3. Schematic view of the cylindrical heat pipe

This experiment was conducted for basic heat transfer research. The essential factor for this research is mathematical simulations in the Ansys program in Fluent. It is necessary to examine the basic phenomena occurring in the heat pipe to define the heat transfer process through the heat pipe in this program. Based on this analysis, designing a material with similar properties to the heat pipe is possible. The newly created heat pipe replacement material shows us the heat transfer basics through a heat pipe under different conditions. We determine the possibility of substituting heat pipe with another material with some parameter changes at this simulation. We have approximated to natural conditions of the heat pipe. This simulation is valid only for specific heat pipe. Using the ANSYS CFD module helps us get an idea of the course of action activities of the active members and experimental phenomena, which can be optimized based on the results obtained, thus reducing the problem of the experimental measurement. This article forms the basis for creating a series of physical experiments based on CFDs and mathematical models to identify the unrecognized area of the use of heat pipes in their activities and the ongoing phenomena.

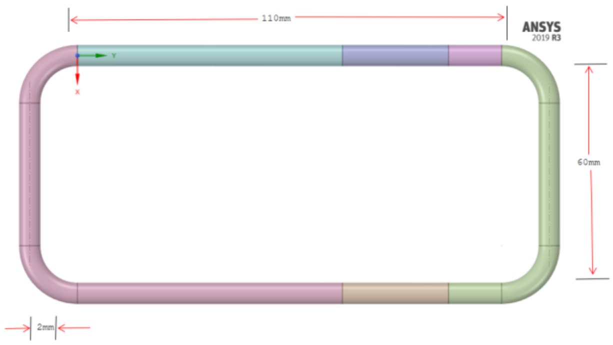

Figure 4. Heat Pipe Model in Ansys

Analysis and Results

Analysis of the performance of CLPHPs is done using the computational fluid dynamics method. This geometry is modeled in 3D in Ansys SpaceClaim. A schematic diagram of the geometry is shown in figure 4. The channel's length and breadth (here, channel instead of pipe is said as the model is in 3D) are 110 mm and 60 mm, respectively, and the pipe is assumed to be made of copper. Water and water vapor are taken as the working fluid, which flows in width 2 mm.

After creating geometric models and meshing has been done in Ansys. Then the model was analyzed by varying the wall heat flux at the evaporator for a particular filling ratio.

Description	Density	Dynamic Viscosity	Specific Heat	Thermal Conductivity
Units	kg/m3	kg/ms	J/kgK	W/mK
Symbol	P	P	Cp	k
Water liquid	1000	0.001003	4182	0.6
Water vapor	0.5542	0.0000134	2014	0.0261
Ethyl alcohol liquid	790	0.0012	2470	0.182
Ethyl alcohol vapor	2.06	0.0000108	2407	0.0145

The two cases of the working fluid were considered. The working fluid taken into consideration was water-water vapor and ethyl alcohol-ethyl alcohol vapor. Figure 5 shows the contour of phases of the working fluid. This contour shows the fraction of water and water vapor inside the channel. The oscillating behavior of working fluid has been shown by using this counter. As can be seen from the figures, the vapor slug moves to and from at different time intervals. It is also concluded that when the liquid slug and the vapor slug move forward, it carries out the heat from the evaporator and transports heat flux to the condenser end by oscillating behavior. During this process, there is a phase change from the liquid phase to the vapor phase and vice versa.

Figure 5: Static Temperature (Mixture)

Figure 6: Turbulent Energy (Mixture)

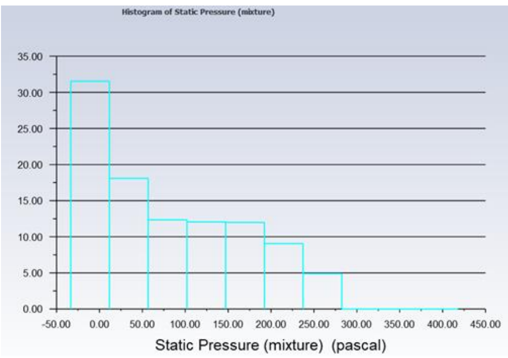

Figure 7: Histogram of Static Pressure (Mixture)

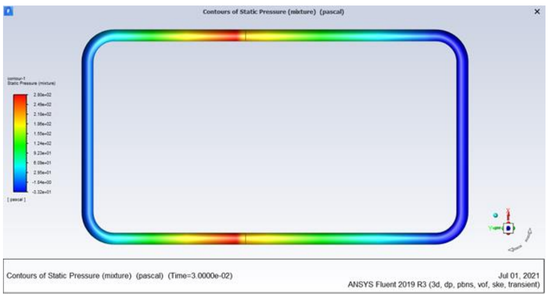

Figure 8: Static Pressure

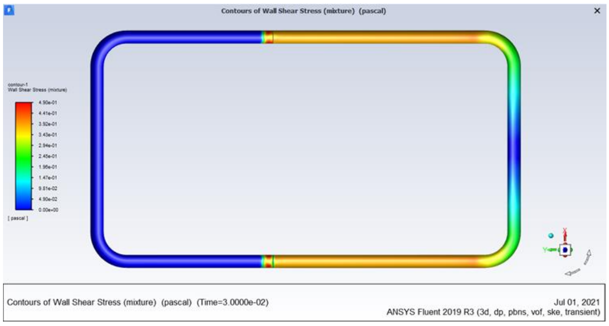

Figure 9: Wall Shear Stress (Mixture)

Table 1 shows the heat flux output at the condenser for different values of heat flux input at the evaporator. The working fluid is taken as a two-phase fluid, i.e., water liquid and water vapor. From the table, we observed that for the heat flux input, the heat flux output variation starts earlier than the lower value of heat flux input.

Table 1: Heat flux output at the condenser

Time in sec	Heat output(W) for 30W input	Heat output(W) for 50W input	Heat output(W) for 100W input
0	0	0	0
5	20.64159	19.08212	19.84356
10	17.98927	17.16788	16.95148
15	17.26441	15.49101	15.17172
20	14.96384	15.53616	13.36375
25	13.95291	18.2872	12.16009
30	12.31902	17.24688	10.7149
35	10.89966	14.9366	9.827559
40	9.511117	13.29477	8.606341
45	8.434875	11.92502	7.790276
50	10.46197	10.30404	7.8195
55	9.251165	9.76943	16.05724
60	8.536623	9.123188	11.40452
65	8.443436	15.48048	13.83295
70	8.877634	11.19273	10.04448
75	6.310759	11.29016	9.305625
80	6.006869	12.6132	11.36196
85	5.281271	9.774879	8.08682
90	5.362241	8.251593	7.841149
95	5.678013	7.048686	6.656506
100	4.799042	9.553208	5.779629
105	4.066377	8.059357	5.144253
110	3.831323	5.572752	6.739488
115	3.743459	5.718899	5.833715
120	3.921056	5.078343	3.893465
125	4.998725	5.107701	5.368751
130	2.965296	3.840414	5.336428
135	2.583455	3.610587	4.879534
140	3.927177	3.879366	3.528817
145	2.836003	3.493398	3.865195
150	2.190431	3.140001	3.911274
155	1.879695	3.319992	3.293952
160	1.722643	2.635528	2.797819
165	1.684039	2.914893	2.938489

170	1.635763	1.892423	2.683431
175	1.976357	1.72561	2.203906
180	1.831121	1.717581	1.841486
185	2.181299	1.506687	1.497033
190	1.615289	1.280394	1.357307
195	1.604695	1.262742	1.245869
200	1.59982	1.346909	1.128268

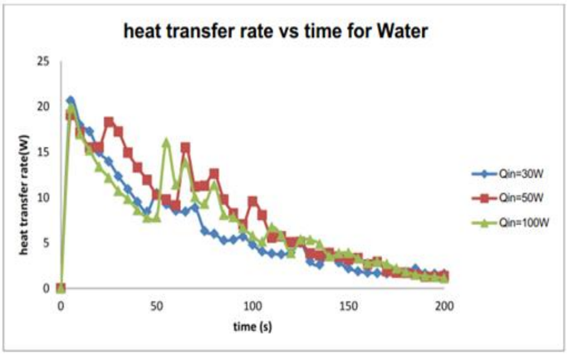

Figure 10: Heat Transfer Rate vs. Time for Water

Figure 10 shows the heat flux variation at the condenser with time for different heat fluxes at the evaporator. the heat transfer behavior is oscillating, can be seen in the graph, which satisfies the thermosyphon phenomenon that occurs in CLPHPs.

Table 1 shows the heat flux output at the condenser for different values of heat flux input at the evaporator. The working fluid is taken as a two-phase fluid, i.e., Ethyl alcohol liquid and ethyl alcohol vapor. When we compare the data for heat flux out for 30W of heat flux input, we found that the variation in the output heat flux for ethyl alcohol starts earlier than water. It has also been observed that the fluctuation rate in alcohol is higher than the water. So, oscillation is faster in the case of alcohol than water.

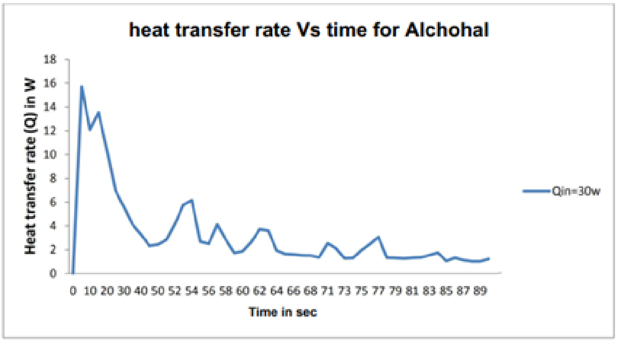

Figure 11: Heat transfer rate vs time or Alchohal

Figure 11 shows the heat flux variation at the condenser with time for different heat fluxes at the evaporator. It is visible from the graph that the frequent oscillation has been attended much earlier than the water. Moreover, it has been observed that the oscillation occurs in a short time interval compared to water.

Conclusion

This work investigates the flow and heat transfer phenomena in a closed loop pulsating heat pipe through the CFD methodology. In addition, the effects of heat flux at the evaporator and different working fluids have also been studied. the conclusion of this analysis as follows.

There is pressure variation inside the tube because of the increase in the volume of the working fluid by absorbing heat at one end, which causes the transport of vapor slug and liquid. the oscillating behavior of working fluid becomes more frequent in a specific time of interval, so the cooling effect more and at some time it less because oscillation in heat flux at the output. Alcohol attends frequent oscillation earlier than water, which signifies that fluid with lower specific heat gives a cooling effect much earlier than the fluid with higher specific heat. The oscillation starts in lesser time for a higher value of input heat flux than the lower value of heat input.

REFERENCES

[1] A. A. Alammar, R. K. Al-Dadah, and S. M. Mahmoud, "Numerical investigation of effect of fill ratio and inclination angle on a thermosiphon heat pipe thermal performance," Appl. Therm. Eng., vol. 108, pp. 1055–1065, 2016, doi: 10.1016/j.applthermaleng.2016.07.163.

[2] G. Batalha Leoni, T. Suaiden Klein, and R. de Andrade Medronho, "Assessment with computational fluid dynamics of the effects of baffle clearances on the shell side flow in a shell and tube heat exchanger," Appl. Therm. Eng., vol. 112, pp. 497–506, 2017, doi: 10.1016/j.applthermaleng.2016.10.097.

[3] J. K. Calautit and B. R. Hughes, "A passive cooling wind catcher with heat pipe technology: CFD, wind tunnel and field-test analysis," Appl. Energy, vol. 162, pp. 460–471, 2016, doi: 10.1016/j.apenergy.2015.10.045.

[4] K. S. Arjun and K. B. Gopu, "Design of Shell and Tube Heat Exchanger Using Computational Fluid Dynamics Tools," vol. 3, no. 7, pp. 8–16, 2014.

[5] J. K. Calautit, H. N. Chaudhry, B. R. Hughes, and S. A. Ghani, "Comparison between evaporative cooling and a heat pipe assisted thermal loop for a commercial wind tower in hot and dry climatic conditions," Appl. Energy, vol. 101, pp. 740–755, 2013, doi: 10.1016/j.apenergy.2012.07.034.

[6] H. W. Chiou, Y. M. Lee, H. H. Hsiao, and L. C. Cheng, "Thermal modeling and design on smartphones with heat pipe cooling technique," IEEE/ACM Int. Conf. Comput. Des. Dig. Tech. Pap. ICCAD, vol. 2017-Novem, pp. 482–489, 2017, doi: 10.1109/ICCAD.2017.8203816.

[7] Hariharan N, "Cfd Thermal Analysis on Laptop Cooling System Using Loop Heat Pipe Technology," Int. J. Res. Eng. Technol., no. 2319–1163, 2014.

[8] H. H. Hsiao, H. W. Chiou, and Y. M. Lee, "Multi-angle bended heat pipe design using X-architecture routing with dynamic thermal weight on mobile devices," Proc. Asia South Pacific Des. Autom. Conf. ASP-DAC, pp. 70–75, 2019, doi: 10.1145/3287624.3287666.

[9] H. Hassan Al-Ghazali, M. Wahhab. Aljibory, and T. Habeeb Alkharasani, "Numerical and Experimental Study the Effect of Solid Particles Flow on Heat Pipe Performance," Int. J. Eng. Technol., vol. 7, no. 4.30, p. 502, 2018, doi: 10.14419/ijet.v7i4.30.25770.

[10] C. N. Huang, K. L. Lee, C. Tarau, Y. Kamotani, and C. R. Kharangate, "Computational fluid dynamics model for a variable conductance thermosyphon," Case Stud. Therm. Eng., vol. 25, no. March, p. 100960, 2021, doi: 10.1016/j.csite.2021.100960.

[11] J. Wang, Y. Gan, J. Liang, M. Tan, and Y. Li, "Sensitivity analysis of factors influencing a heat pipe-based thermal management system for a battery module with cylindrical cells," Appl. Therm. Eng., vol. 151, no. February, pp. 475–485, 2019, doi: 10.1016/j.applthermaleng.2019.02.036.

[12] V. R. Pawar and S. Sobhansarbandi, "CFD modeling of a thermal energy storage based heat pipe evacuated tube solar collector," J. Energy Storage, vol. 30, no. January, p. 101528, 2020, doi: 10.1016/j.est.2020.101528.

[13] A. Soman and Y. Shastri, "Optimization of novel photobioreactor design using computational fluid dynamics," Appl. Energy, vol. 140, pp. 246–255, 2015, doi: 10.1016/j.apenergy.2014.11.072.

[14] C. Yue, Q. Zhang, Z. Zhai, and L. Ling, "CFD simulation on the heat transfer and flow characteristics of a microchannel separate heat pipe under different filling ratios," Appl. Therm. Eng., vol. 139, pp. 25–34, 2018, doi: 10.1016/j.applthermaleng.2018.01.011.

[15] P. Assistant, "Computational Fluid dynamics analysis and validation of the effect of angle of inclination of the pipe on temperature of the fluid for Constant surface heat flux condition," pp. 15–23, 2017.

[16] A. Sözen, M. Gürü, A. Khanlari, and E. Çiftçi, "Experimental and numerical study on enhancement of heat transfer characteristics of a heat pipe utilizing aqueous clinoptilolite nanofluid," Appl. Therm. Eng., vol. 160, no. June, p. 114001, 2019, doi: 10.1016/j.applthermaleng.2019.114001.

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