Performance Analysis of Pulsating Heat Pipe

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***Abstract*--This presents a computational study on the heat transfer characteristics of pulsating heat pipe. However modeling of a CLPHP system in GAMBIT has many challenging issues due to the complexity and multi-physics nature of the system. So, the pulsating heat pipe modeled here has no wick material inside it as it present in heat pipe. The pulsating heat pipe has no complex structure so it is to be modeled. Water-water vapor and ethyl alcohol ant ethyl alcohol vapor are taken as the working fluid and heat flux is supplied at the inlet. Phenomena such as nucleation boiling, formation of slug and propagation of inertia wave were observed in the pulsating heat pipe. Also the analysis has been done to know the behaviour of pulsating heat pipe under varying supply of heat flux at the inlet (evaporator).for this, the output heat flux is obtain at outlet (condenser) and find out how the heat flux is varying for different heat flux and the different working fluid.**

Keywords— Pulsating Heat Pipe, CFD Modeling, CFD Programs, Boundary Conditions

I. INTRODUCTION

Pulsating heat pipes typically suited for microelectronics cooling consists of a plain meandering tube of capillary dimensions with many U-turns and joined end to end. The pipe is first evacuated and then filled partially with a working fluid. If the diameters of Close Loop Pulsating heat pipe is not too large, the fluid distributes itself into an arrangement of liquid slugs separated by vapor bubbles. One end of this tube bundle receives heat transferring it to the other end by a pulsating action of the liquid–vapor/slug-bubble system. The liquid and vapor slug/bubble transport is caused by the thermally induced pressure pulsations inside the device and no external mechanical power is required. 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 transfer from evaporator to condenser by the means of pulsating action of 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 some of the parallel channels. For Pulsating heat pipes , no external power source is needed to either initiate or sustain the fluid motion or the transfer of heat. The purpose of this project is to understand how Pulsating heat pipes operate and to be able to understand how various parameters (geometry, fill ratio, materials, working fluid, *etc.)* affect its performance. Understanding its operation is further complicated by the non-equilibrium nature of the evaporation and condensation process, bubble growth and collapse and the coupled response of the multiphase fluid dynamics among the different channels.

II. PULSATING HEAT PIPE

Pulsating heat pipe has many numbers of U-turns of tube with capillary diameter. These tubes are evacuated and partially filled with the working fluid. When the diameter of the tube is so small, preferably <2mm then the working fluid distributed itself in the form of vapor slug and liquid slug. When it compare with the convectional heat pipe, it has no wick material inside the tube.

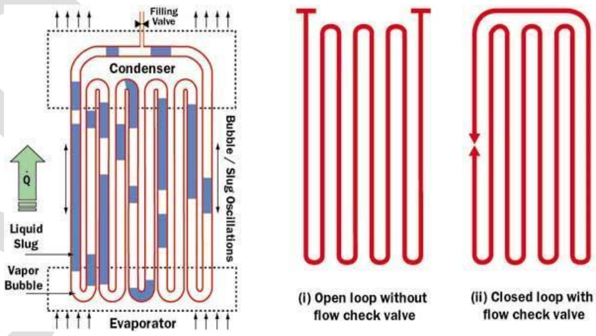

Fig.1Schematic diagram of pulsating heat pipe

III. CFD MODELING

The invention of high speed digital computers, combined with the development of accurate numerical methods for solving physical problems, has revolutionized the way we study and practice fluid dynamics and heat transfer. This approach is called Computational Fluid Dynamics or CFD in short, and it has made it possible to analyze complex flow geometries with the same ease as that faced while solving idealized problems using conventional methods. CFD may thus be regarded as a zone of study combining fluid dynamics and numerical analysis. Historically, the earlier development of CFD in the 1960s and 1970s was driven by the need of the aerospace industries. Modern CFD, however, has applications across all disciplines – civil, mechanical, electrical, electronics, chemical, aerospace, ocean, and biomedical engineering being a few of them. CFD substitutes testing and experimentation, and reduces the total time of testing and designing. Fig. gives the overview of the CFD modeling process.

CFD PROGRAMS: The development of affordable high performance computing hardware and the availability of user-friendly interfaces have led to the development of commercial CFD packages. Before these CFD packages came into the ordinary use, one had to write his own code to carry out a CFD analysis. The programs were usually different for different problems, although some part of the code of one

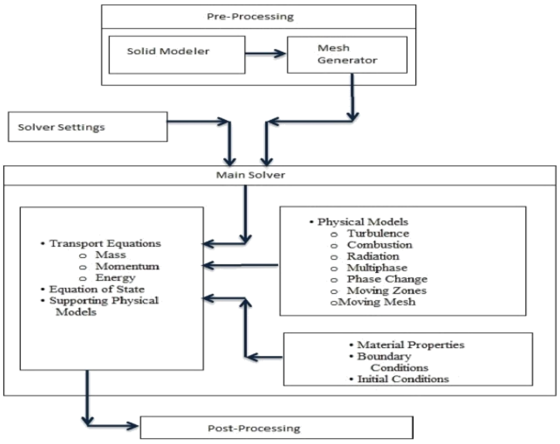

Fig. 2Overview of Modeling Process

program could be used in another. The programs were inadequately tested and reliability of the results was often questioned. Today, well tested commercial CFD packages not only have made CFD analysis a routine design tool in industry, but are also helping the research engineer in focusing on the physical system more effectively.

IV. PERFORMANCE ANALYSIS OF PULSATING HEAT PIPE

Analysis of the performance of Heat pipe is done using computational fluid dynamics method. For this geometry is modeled in 2D in Gambit . A schematic diagram of the geometry is shown in figure . The length and the breadth of the channel (here channel instead of pipe is said as model is in 2D) is 110 mm and 60 mm respectively and the pipe is assumed to be made of copper. Water and water vapor is taken as the working fluid which flows in the channel of width 2 mm.

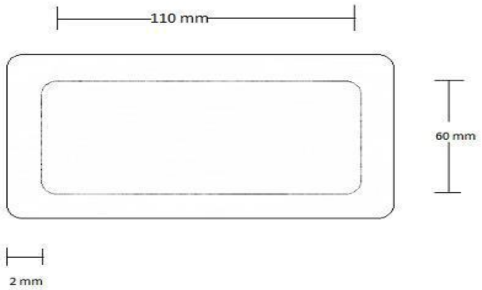

Fig3 Schematic diagram of geometry considered for the analysis

After creating geometric models and meshing has done in Gambit . Then the model was analyzed by varying the wall heat flux at evaporator for a particular filling ratio. The two case of the working fluid was considered. The working fluid taken in consideration was water-water vapor and ethyl alcohol-ethyl alcohol vapour

V. GOVERNING EQUATIONS

Applying boundary conditions, the governing equations for convective heat transfer are as follows:
The critical Bond number (or Eötvös) criterion gives the tentative design rule for the diameter

$$(\text{Eö})_{crit} = (Bo)^2{}_{crit} \approx \frac{D^2 . g.(\rho_{liq} - \rho_{vap})}{\sigma} \approx 4 \qquad (1)$$

$$D_{crit} \approx 2.\sqrt{\frac{\sigma}{g.(\rho_{liq} - \rho_{vap})}} \qquad (2)$$

VI. VOLUME OF FLUID

In computational fluid dynamics, the Volume of fluid method is one of the most well-known methods for volume tracking and locating the free surface. The motion of all phases is modeled by solving a single set of transport equations with appropriate jump boundary conditions at the Interface. The VOF model can model two or more immiscible fluids by solving a single set of momentum equations and tracking the volume fraction of each of the fluids throughout the domain. It is generally used to figure out a time dependent solution but for problems which are concerned with steady state solution; it is possible to perform a steady state calculation. A steady state VOF calculation is practical only when the solution is independent of the initial conditions and there are distinct inflow boundaries for the individual phases. Typical applications include the motion of large bubbles in a liquid, the motion of liquid after a dam break, the prediction of jet breakup, and the steady or transient tracking of any liquid-gas interface. In general, the steady
or transient VOF formulation relies on the fact that two or more fluids (or phases) are not interpenetrating.

Volume Fraction

In VOF model the variables and properties in any given cell are either purely representative of one of the phases, or representative of a mixture of the phase, depending upon the volume fraction values. In other words, if the q^{th} fluid's volume fraction in the cell is denoted as α_q then the following three conditions are possible:

- $\alpha_q = 0$: the cell is empty(of the q^{th} fluid).
- $\alpha_q = 1$: the cell is full (of the q^{th} fluid).
- $0 < \alpha_q < 1$: the cell contains the interface.

Boundary Conditions

The analysis of the model has been done under two sections.
a) In the first case the water and water vapor is taken as the working fluid with filling ratio of 70 % and the heat flux of 30W, 50W and 100W has applied at evaporator. The initial working fluid temperature is 300K and the ambient temperature is 298K.
b) In the second case the ethyl alcohol and ethyl alcohol vapor is taken as the working fluid with filling ratio of 70 % and the heat flux of 30W, 50W and 100W has applied at

evaporator. The initial working fluid temperature is 300K and the ambient temperature is 298K.

In the work reported here, water and water vapor and also ethyl alcohol liquid and ethyl alcohol vapor as the working fluid for the analysis. Fluid properties are assumed to be constant with temperature. The properties of water and water vapor and also ethyl alcohol liquid and ethyl alcohol vapor considered for the analysis is given in table

The temperature of the fluid is taken as 300K and the convective heat transfer is considered at the condenser. The ambient temperature is 298K.

Table Properties of working fluids

Description	Symbol	Water liquid	Water vapor	Ethyl alcohol liquid
Density	P	1000	0.5542	790
Dynamic Viscosity	μ	0.001003	0.0000134	0.0012
Specific Heat	C_p	4182	2014	2470
Thermal Conductivity	K	0.6	0.0261	0.182

CONCLUSION

Through the CFD methodology, this work investigates the flow and heat transfer phenomena in a closed loop pulsating heat pipe. Effects of heat flux at evaporator and different working fluid have been also studied. Several important conclusions could be drawn from the present simulations and would be presented as follows

- There is pressure variation inside the tube because of increase in volume of the working fluid by absorbing heat at one end which causes the transport of vapor slug and liquid.

- After a certain time of interval, the oscillating behavior of working fluid becomes more frequent which causes oscillation in heat flux at the output that means at some moment cooling effect will be more and at some time it will be less.

- Alcohol attends frequent oscillation earlier as compared to water which signifies that fluid with lower specific heat will give cooling effect much earlier than the fluid with higher specific heat.

- For higher the value of input heat flux, the oscillation starts in lesser time as compare to the lower value of heat input.

REFERENCES

[1] Khandekar S. and Groll M., On the Definition of Pulsating Heat Pipes: An Overview, Proc. 5th Minsk Int. Conf. (Heat Pipes, Heat Pumps and Refrigerators), Minsk, Belarus, 2003.

[2] Khandekar S. and Groll M., An Insight into Thermo-Hydraulic Coupling in Pulsating Heat Pipes, Int. J. of Thermal Sciences, ISSN 1290- 0729, Vol. 43/1, (2004): pp. 13-20

[3] Khandekar S., Manyam S., Groll M. and Pandey M., Two-phase Flow Modeling in Closed Loop Pulsating Heat Pipes, Proc. 13th Int. Heat Pipe Conf., Shanghai, China, 2004.

[4] Khandekar S., Thermo-hydrodynamics of Closed Loop Pulsating Heat Pipes, Doctoral Dissertation, Universität Stuttgart, Germany, 2004.

[5] Gi. K., Sato F. and Maezawa S., Flow Visualization Experiment on Oscillating Heat Pipe, Proc. 11th Int. Heat Pipe Conf., (1999): pp. 149- 153, Tokyo, Japan

[6] Lee W., Jung H., Kim J. and Kim J., Flow Visualization of Oscillating Capillary Tube Heat Pipe, Proc. 11th IHPC, (1999): pp. 355-360,Tokyo, Japan

[7] Tong B. Y., Wong T. N. and Ooi K., Closed- Loop Pulsating Heat Pipe, Applied Thermal Engineering, ISSN 1359-4311, Vol. 21/18, (2001): pp. 1845-1862

[8] Qu W. and Ma T., Experimental Investigation on Flow and Heat Transfer of a Pulsating Heat Pipe, Proc. 12th Int. Heat Pipe Conf., (2002): pp. 226- 231, Moscow, Russia

[9] Khandekar S., Groll M., Charoensawan P. and Terdtoon P., Pulsating Heat Pipes: Thermofluidic Characteristics and Comparative Study with Single Phase Thermosyphon, Proc. 12th Int. Heat Trans. Conf., ISBN-2-84299-307-1, Vol. 4, (2002):pp. 459-464, Grenoble, France

[10] Charoensawan P., Heat Transfer Characteristics of Closed Loop Oscillating Heat Pipes, Ph.D. Thesis, Chiang Mai University, Chiang Mai, Thailand, 2003.

[11] Groll M. and Khandekar S., Pulsating Heat Pipes: Progress and Prospects, Proc. 3rd Int. Conf. on Energy and Environment, ISBN 7- 5323-7335-5/TK-22, Vol. 1, (2003): pp. 723-730, Shanghai, China.

[12] Khandekar S., Dollinger N. and Groll M., Understanding Operational Regimes of Pulsating Heat Pipes: An Experimental Study, Applied Thermal Engineering, ISSN 1359- 4311, Vol. 23/6, (2003): pp. 707-719

[13] Khandekar S., Schneider M., Schäfer P., Kulenovic R. and Groll M.,Thermofluiddynamic Study of Flat Plate Closed Loop Pulsating Heat Pipes, Microscale Thermophysical Engg., ISSN 1089-3954, Vol. 6/4, (2002): pp. 303-318

[14] Maezawa S., Gi A., Minamisawa K. and Akachi H., Thermal Performance of Capillary Tube Thermosyphon, Proc. 9th Int. Heat Pipe Conf., Vol. 2, (1995):pp. 791-795, Albuquerque, New Mexico

[15] Maezawa S., Nakajima R., Gi K. and Akachi H., Experimental Chaos in Oscillating Capillary Tube Heat Pipes, Preprints 10th Int. Heat Pipe Conf., Vol. 3/4, Session F, Stuttgart, Germany, 1997.

[16] Akachi H. and Polášek F., Thermal Control of IGBT Modules in Traction Drives by

[17] Pulsating Heat Pipes, Preprints 10th Int. Heat Pipe Conf., Vol. 3, (1997): pp. 8-12, Stuttgart, Germany