CFD Numerical Analysis of Performance Parameters for Closed Loop Pulsating Heat Pipe using ANSYS FLUENT

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Abstract- Heat Pipe is used for Cooling purpose in Electronics Devices. It is mainly of two type a) Open Loop Heat Pipe and Closed loop Heat Pipe. Closed loop pulsating heat pipe is a device which combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. The performance of Heat pipe depends on various parameters like number of turns, inclination angle, working fluid, filling ratio etc. In this project Analysis of performance parameters was done using CFD on ANSYS Fluent. The results of CFD Analysis are compared with the experimental results mentioned in the various research papers. Also the performance is analyzed with different inputs with the help of Color Contours. In this Study the Geometry of CLPHP with 10 Number of turns was modeled having Inside and Outside diameter of pipe are 3 mm and 4 mm respectively. Length of pipe is 450 mm. The gap between the pipes is 12 mm. Total length of the pipe is 6 m. For getting better results grid independent study is done and element size 5 mm, 2 mm and 3 mm are selected. For Simulation different kind of mesh has been checked and 0.5 mm element size mesh is found optimum and selected for next analysis. Numerical model developed is very useful in observing and analyzing the working phenomenon of CLPHP. Mostly analysis of closed loop pipe was performed in vertical position with different refrigerants having different filling ratio. When the filling ratio of the CLPHP was marked as 50%, highest performance curve was obtained. Thermal contact resistance offered by the CLPHP at this filling ratio was found to be minimum leading to high performance of structure.

I. INTRODUCTION

Heat pipe is device used to transmit heat between solid surfaces. It act as a solid conductor but in real it uses the principle of heat transfer and phase transition. The refrigerant turns into vapor at the higher temperature interface of a heat pipe by absorbing latent heat in contact. After that by releasing heat the vapor condenses into liquid while traveling along the cold interface of heat pipe. The liquid comes to the hot interface because of capillary action, gravity, or centrifugal force, and the cycle repeats again and again. The dependence of effective thermal conductivity of heat pipe is largely on its length, and it can approximately enhanced up to 100 kW/ (m·K) for long heat pipes, which is comparatively very high with 0.4 kW/ (m·K) for copper pipes. [1]. Pulsating heat pipe mainly has capillary diameter and consists of numbers of U-turns of tube. These tubes are partially filled with working fluid after evacuation for creating vacuum. Due to so small diameter of the tube, preferably <2mm the working fluid scattered itself equally in the form of vapor slug and liquid slug [2]. It has no wick material inside the tube when it is compared with the convectional heat pipe. The size of the heat can be made very small of the order of various electronic equipments. If the space is limitation than solid conductors are suitable for heat transfer from critical zone to non critical zone. But the heat transfer capability of solid conductors is generally less. Closed loop pulsating heat pipe is a good replacement for solid conductors because it is having refrigerant circulating in it but the system is as small as solid conductors. That’s why it is being used in electronic devices where the use of blowers, fans etc. are limited.

Closed loop pulsating heat pipe:

The heat pipes whose thermal performance was governed by its strong thermal-hydraulic coupling were termed as closed loop pulsating heat pipes (CLPHPs). Close Loop Pulsating heat pipes (CLPHPs) were very well suited in microelectronics cooling consisting of a plain very thin and delicate capillary tube having many U-turns joined at each ends to each other. The pipe was initially emptied and further was filled partially with working fluid. Due to small diameter of Close Loop Pulsating heat pipe, the fluid distributes itself into an arrangement of liquid slugs and vapor bubbles. This liquid–vapor/slug-bubble system receives heat from one end of tube bundle transferring it to the other end by a pulsating action of the fluid. The type of fluid and the operating pressure inside the pulsating heat pipe decides the operating temperature of the heat pipe. The region between evaporator and condenser was assumed to be adiabatic. The heat was transferred 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. Close Loop Pulsating heat pipes (CLPHPs) doesn't require any external power source for either creating or maintaining the fluid motion or the transfer of heat.

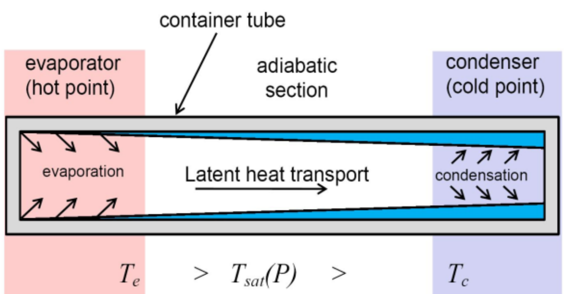

Fig.1 Principle of CLPHP

II NUMERICAL MODEL

The first step of a Computational fluid analysis is geometry creation. Analysis of the performance of CLPHPs is done using computational fluid dynamics method. For this geometry was developed in 2D in Solid Works 2016x64. Fig. 3 gives the details of the Closed Loop Pulsating Heat Pipe considered in the study. The specifications of the geometry were taken on the basis of experimental work done by Dukare et al. in their research paper mentioned in ref. no.[8]. Number of turns is taken as 10. Inside and Outside diameter of pipe are 3 mm and 4 mm respectively. Length of pipe is 450 mm and 12 mm is the gap between the pipes. Total length of the pipe is taken as 6 m.

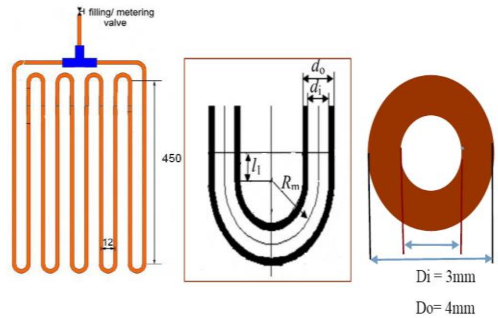

Fig. 2 Geometry of CLPHP

Geometry Creation

Following were the steps for the geometry creation.

Step-1: Opened part drawing window in solid works software for sketching and modeling.

Step-2: With line and arc commands in sketch option the drawing of 10 turn closed loop lined sketch is created by taking 16 mm distance between the lines so that 12 mm gap can be maintained after creating 4 mm diameter pipe.

Step-3: Reference plane taken at a point on a line of loop on which two concentric circles of 3mm and 4mm diameters drawn.

Step-4: With the help of composite curve this curve is made integral.

Step-5: In features option with the help of swept boss command the pipe construction is done.

Step-6: Save this geometry in IGS format so that it can be opened in ANSYS FLUENT.

Fig.3 is the computer screenshot of the developed geometry.

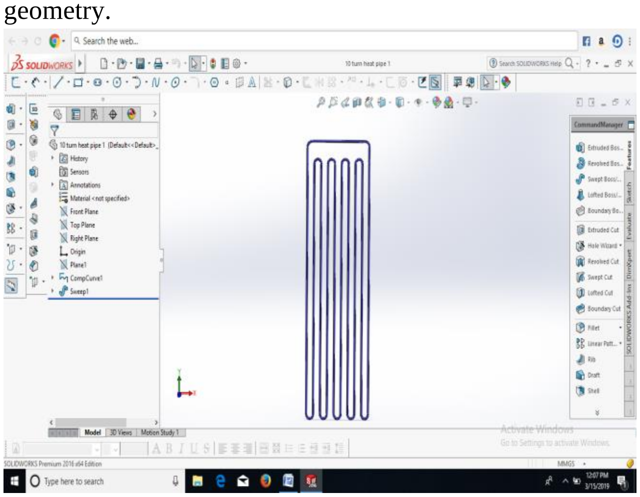

Fig.3 Modeling of 10 turns closed loop heat pipe

Design Modular in ANSYS

Step-1: Imported the geometry in ANSYS Design Modular.

Step-2: Unfreeze the geometry then slice the geometry in to two halves. One half patched liquid refrigerant and other half patched air. Names were given the two parts- Liquid refrigerant and air.

Grid/Mesh Generation

As mentioned in Fig.4 for achieving better results grid independent study is done, element size .5 mm , 2 mm and 3 mm are selected . Different kind of mesh has been checked for simulations and 0.5 mm element size mesh is found optimum and selected for further analysis.

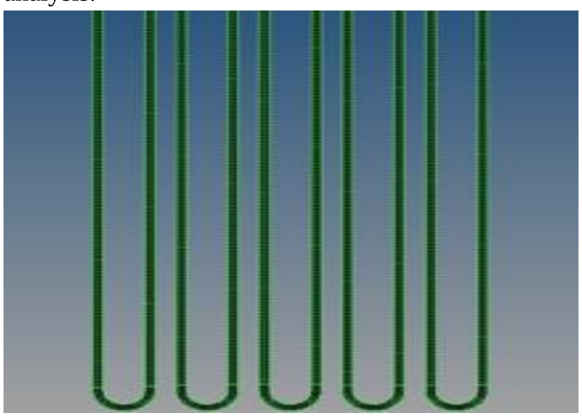

Fig. 4 0.5 mm Mesh closed loop heat pipe

In named section different surfaces of geometry is given the names like Heater, Condenser, Adiabatic section etc.

Setup Domain, Boundary Conditions and Initialization:

Step-1: In setup domain a lot of functions are activated like Transient problem, gravity, Volume of fluid, k epsilon, enhanced wall treatment, thermal effects and curvature correction.

Step-2: Material for the heat pipe, working fluid/refrigerants are selected. Operating conditions like pressure ambient temperature etc are set in cell zone condition.

Step-3: Other Boundary conditions are taken. Length of pipe is 450 mm and 12 mm is the gap between the pipes. Total length of the pipe is taken as 6 m. Inside and Outside diameter of pipe are 3 mm and 4 mm respectively.

Table 1 gives the details of the Boundary conditions of different operating parameters.

Operating Parameters	Specifications
Working Fluid	R-134a, R-22, R-32
Filling Ratio	83%, 70%, and 50% resp.
Inlet temperature	32-33^0 C
Condenser Temperature	37-49^0 C
Heat Flux (W)	109.08, 133.44, 145.44, 181.8, 254.52, 327.25
Wall Conditon	Adiabatic

Table 1 Boundary conditions[10]

Step-4: Initialize and calculation run is done.

Analysis of Operating Parameters:

The closed loop heat pipe which is meshed with 1 mm mesh size is analyzed with ANSYS Fluent software with different boundary conditions and refrigerants. Initially in Vertical arrangement different working fluids were analyzed at 50% FR to find optimum refrigerant. After that different filling ratios were analyzed namely 50%, 70% and 83% respectively to get best Filling Ratio. At last Horizontal arrangement was taken to find out the effects of inclination of closed loop heat pipe.

Various Temperature Contours are obtained by giving various inputs. These temperature contours are represented by color coding. It is also called as color contours. On the basis of these temperature contours, we can draw different curves for analyzing the performance and the effects of parameters on the performance of the Heat Pipe. With different boundary conditions like Evaporator temperature, Condenser Temperature, filling ratios etc, different contours are achieved. With the help of these temperatures and input quantities, other quantities and parameters like Heat Flux, Contact thermal Resistance etc. can be found out.

III. RESULTS AND DISCUSSION

This Chapter deals with optimization of various parameters like Filling ratios, orientation etc.to maximize the performance of closed Loop Pulsating Heat Pipe. First Vertical arrangement was analyzed and then Horizontal arrangement. The results are observed under following headings-

1) Vertical Arrangement
2) Horizontal Arrangement

Vertical Arrangement: In this section the model was analyzed for different filling Ratios 50%, 70% and 83% in order to find out optimum filling ratio.

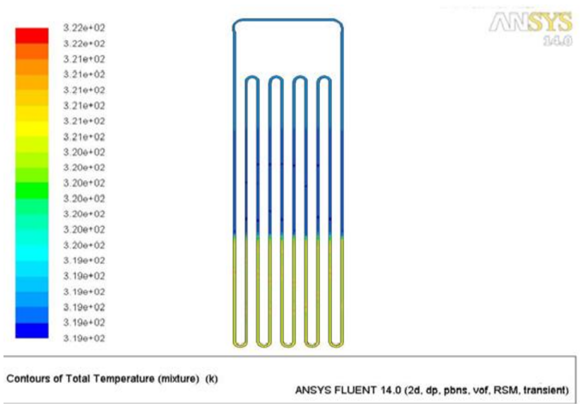

Fig. 5 Temperature Contour in CLPHP

For 83% FR: Fig.6 represents the comparison between the theoretical heat flux obtained on analysis with 83% filling ratio working fluid R-134a and that with R-22.Theoretical data is obtained from the analysis of the modelling of the closed loop pulsating heat pipe drawn with same dimensions as earlier mentioned and the boundary conditions are the output and input temperature of the fluid is provided.

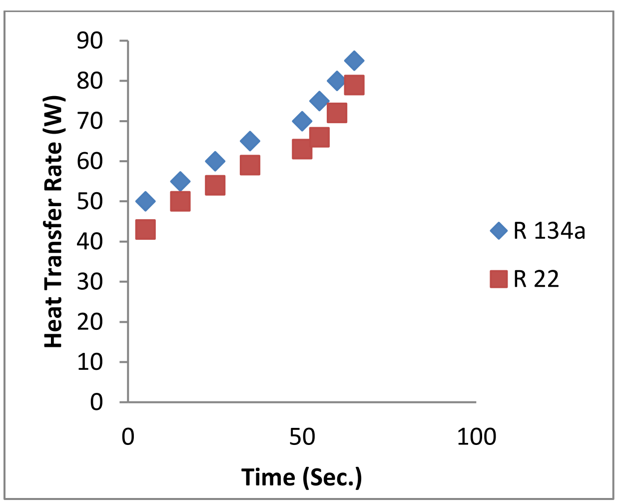

Fig. 6 Comparison on Heat Transfer Rate with 83% FR

Continuous working of the closed loop heat pipe may also result in the over use of the coolant and the filling ratio will decrease as a result of which only vapor form of the coolant will be left and the R-134a will totally vaporized. This situation obviously needs to be avoided. But obviously it can be used for continuous removal of heat as it starts from the beginning so it remains good in the form of a cycle.

For 70% FR: It is been found that that the heat transfer rate increases with the time. Also on an average with R134a Fluid the Heat Transfer with 70% FR is higher than the heat Transfer with 83% by 10.0%.

% Increment in Heat Transfer from 83% FR to 70% FR = 10%

For 50% FR: On an average with R134a Fluid the Heat Transfer with 50% FR is higher than the heat Transfer with 70% by 3.7%.

% Increment in Heat Transfer from 70% FR to 50% FR = 3.7%

Effect of Filling Ratio on Contact Thermal Resistance

For 83% FR: Fig.7 represents the comparison between the theoretical contact thermal resistance obtained on analysis with 83% filling ratio and working fluid R-134a and R 22. The theoretical data is obtained from the analysis of the model of closed loop pulsating heat pipe drawn with same dimensions as earlier mentioned and the boundary conditions are the output and input temperature of the fluid is provided.

The thermal resistance of closed loop heat pipe is calculated by following equation-

$$R_{th} = \frac{(T_E - T_C)}{Q} \quad \frac{^0K}{W} \qquad \text{……………………..} \quad 4.1$$

Where T_E = Evaporator temperature (^{0}K)
T_C = Computer Temperature (^{0}K)
Q = Heat Input (W)

The contact thermal resistance for 109.08 W Heat Flux is calculated by equation 4.1. For this case Evaporator and condenser temperature have been listed below.

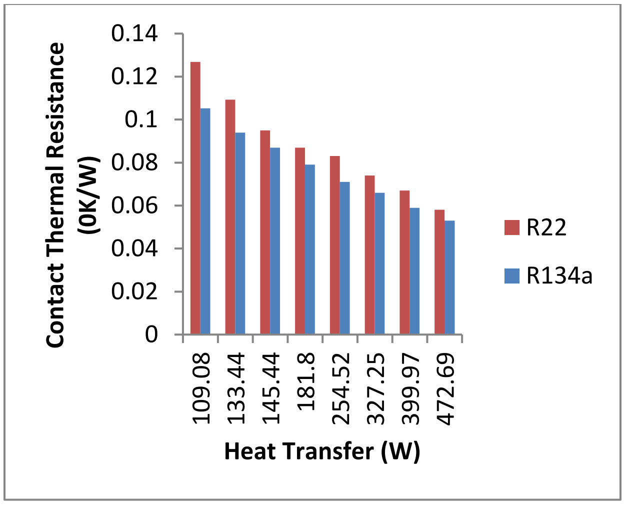

Fig. 7 Thermal contact resistance vs Heat Flux at 83% filling ratio

For 70% FR: The theoretical data is obtained from the analysis of the model of closed loop pulsating heat pipe drawn with same dimensions as earlier mentioned and the boundary conditions are the output and input temperature of the fluid is provided. Avg. % Reduction in Contact Thermal Resistance from 83% FR to 70 FR = 14.4%

For 50% FR: The theoretical data is obtained from the analysis of the model of closed loop pulsating heat pipe drawn with same dimensions as earlier mentioned and the boundary conditions are the output and input temperature of the fluid is provided. On an average with R134a fluid the Contact Thermal Resistance for 50% FR reduce by 9.2 % in comparison with 70% FR.

i.e. Avg. % Reduction in Contact Thermal Resistance from 70% FR to 50 FR = 9.2%

Fig.8 represents the comparison among three Filling Ratios 50%, 70% and 83% respectively on the basis of contact thermal resistance for refrigerant R134a. It is seen that the magnitude of thermal resistance in vertical orientation when 50% Filling Ratio is lower than vertical orientation of 83% and 70% FR. It is also observed that the thermal resistant is decreases as the heat input increases in all filling ratio and orientations. If heat input is low then may be plugs and slugs will not forms. The below mentioned graph represents that at 50% Filling Ratio in vertical orientation the Heat pipe will perform better.

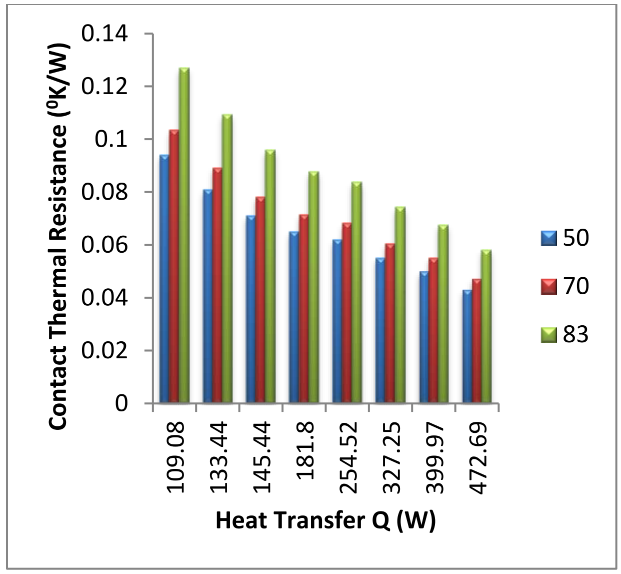

Fig. 8 Thermal contact resistance vs Heat Flux for R134a

Avg. % Reduction in Contact Thermal Resistance from 83% FR to 70 FR = 14.4%

Avg. % Reduction in Contact Thermal Resistance from 70% FR to 50 FR = 9.2%

Horizontal Arrangement

Horizontal closed loop heat pipe is also numerically analyzed using ANSYS FLUENT with specific boundary conditions. Different temperature contours were obtained by simulation of numerical model of Horizontal closed loop pulsating heat pipe. With the help of these temperature contours graphs for thermal resistances and heat transfer were plotted for futher analysis.

Fig.9 represents the variation of contact thermal resistance with Heat transfer when the closed loop pipe is fully horizontal. The values of thermal resistances in horizontal arrangement are slightly lesser than vertical arrangement. That means horizontal arrangement will give better heat transfer.

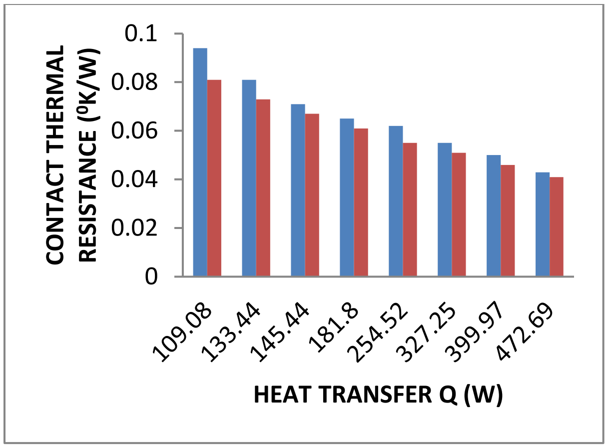

Fig.9 Thermal resistance versus Heat transfer variation with 50% Filling Ratio

IV. CONCLUSIONS

A numerical study on ANSYS FLUENT was done. Some important findings are:

1) Numerical model of closed loop pulsating heat pipe can be developed using ANSYS Fluent.

2) The thermal resistance was decreasing as the heat input increasing. For given evaporator and condenser temperature Heat transfer was increasing with time.

3) In vertical mode of operation 50% Filling Ratio gave optimum performance.

4) Horizontal mode gave maximum heat transfer and minimum thermal resistance.

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