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Thermal Performance of an Grooved and Sintered Heat Pipe

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Abstract : Heat pipes are phase change heat transfer devices used in wide range of heat transport applications due to their high thermal transport capacities with low temperature differences. Heat pipes are especially preferred for electronic cooling applications and aerospace avionics to satisfy high heat transfer rate requirements. The influences of incline angle on the temperature profiles, heat transfer limit of the heat pipe under single heating source, different mass flow rates and at different heat inputs. The heating source shows a pivotal role in the transient characteristics of the grooved heat pipe. The heated zone of the heat pipe shows higher temperature level than that of the non-heated zone, and there is a sharp temperature variation at the transition region of the heating zone and non-heating zone. When heat is imposed at the front end of heat pipe, a dramatic increase of temperature appears soon after the heating power has reached its heat transport limitation. And this limitation can still be increased when the heating source is imposed close to the cooling section as the distance between the heating source and the cooling section decreases.

***IndexTerms* – Grooved heat pipe, Heat Transfer, CFD Analysis of Heat Pipe, Electronics Cooling**

I. INTRODUCTION

By the recent advances in technology, electronic components are getting smaller in size, and the corresponding power dissipated is getting higher and it becomes an important and critical issue for the proper utilization of these devices. Besides traditional heat transport devices and methods, heat pipes have been considered as a favorable alternative [1] not only for thermal management of electronic components [2] but also in space applications [3], heating, ventilating and air-conditioning systems [4] and nuclear applications [5]. As a result of increasing heat pipe utilization, a better understanding of heat pipe characterization is necessary to assess and improve thermal performance. However, it is a challenging task since heat pipes characterization involves simultaneous modelling of different phenomena including phase change free surface capillary flow and heat transfer modeling. Various studies have been done to predict the thermal performance of flat grooved heat pipes that suggest different phase change, flow and heat transfer models. Do et al. [6] developed a mathematical model for predicting the thermal performance of a flat micro heat pipe with a rectangular grooved wick structure. In their study, the effects of liquid–vapor interfacial shear stress, contact angle and the amount of liquid charge were investigated and it was concluded that some common assumptions used in previous studies may be misleading while predicting thermal performance of the heat pipe. *Corresponding author: refaz@metu.edu.tr Lefèvre et al. [7] developed a two-phase flow model and resistance network based thermal model to calculate the liquid and vapor pressures and velocities, the meniscus curvature radius and the temperature in the heat pipe container from the source to the sink region. Heat conduction in each cross section in liquid and solid regions was simulated using thermal resistances which were utilized to calculate the axial temperature distribution. By using two-phase model vapor velocities, the liquid and vapor pressures and the meniscus curvature radius are determined and used for calculate transversal resistances in heat transfer model. Odabaşı [8] developed a model using the 3-D heat transfer equations in both the solid and the liquid, coupled with a simplified 1-D momentum equation. A simplified form of the momentum equation along the heat pipe axis was formulated to calculate the variation of liquid vapor interface radius along the heat pipe which generates the capillary force necessary to drive the flow. Phase change heat transfer from micro region was calculated using the relation obtained from kinetic theory and phase change heat transfer both from micro region and macro region were included in the analysis. Zhang et al. [9] proposed a 1-D thermal resistance network to optimize the performance of a heat pipe with Ω-shaped grooves. In order to optimize the performance, the effect of structural parameters and total thermal resistance on heat transfer capability were investigated.

As electronic devices get smaller, engineers and designers are faced with the growing challenge of keeping up with the need to optimize processing speed within a shrinking form factor. Faster processors necessitate increased power consumption, which generates heat; and smaller form factors necessitate greater miniaturization of the implements used to disperse that heat. These considerations are forcing clever engineers and designers to think in terms of systemic solutions in which every consideration in a device's power equation is examined for greatest optimization. In general, requirements of the power equation demand that heat dissipation must be proportional to the power dissipation of a given device. Power dissipation is the amount of electricity wasted by a device (i.e., power dissipation is dependent on the capacitance of the logic elements, the operating voltage swing, and the operating frequency). Even though the processors in mobile phones, for example, often use just a few hundred milliwatts of electricity, much of this is simply lost to heat.

Conventional methods for cooling electronic equipment include improving the design of printed circuit boards, using thermal interface materials to fill the microscopic air gaps and using of fans. These methods are replaced by integration of heat pipes which provides efficient cooling.

II. METHODOLOGY

- Numerical investigations on Grooved wick heat pipe for heat inputs varying from 100 W to 300 W (in steps of 50W), for inclination angles of 0^{O} to 90^{O} (in steps of 15^{O}) and Mass flow rates 0.01 kg/s, 0.02 kg/s and 0.03 kg/s.
- For the calculated Reynolds Number, Thermal Efficiency, thermal resistance and Heat Dissipation rate at condenser sections.

. The heat pipe set up like inner diameter of 14.0 mm, length 565 mm, tube material is copper and working fluid is water. Inlet (evaporator) boundary condition as heat flux, mass flow rate in the condenser region and outlet temperature boundary condition are used to simulate the heat transfer coefficient and thermal resistance of working fluid at different heat inputs and cooling fluid variation in the condenser jacket.

2.1 ANSYS FLUENT Setup

Numerical simulations were carried out using the commercial CFD software package ANSYS Fluent. The first step taken for after importing the mesh geometry into ANYSYS Fluent involves checking the mesh/grid for errors. Checking the grid assures that all zones are present and all dimensions are correct. When the grid is checked completely and free of errors, a scale and units are assigned. For this study, the grid was created in mm and then scaled to meters. For doing mesh, sweep method is used. In this, the mesh is divided into both quadrilateral and tri-diagonal as shown in the figure 4.3. The element size for evaporator, adiabatic and condenser is taken as 1 mm and for wick and water the element size is taken as 0.5 mm, 155117 nodes and 149580 elements were generated. Once the grid and mesh were set, the solver and boundary conditions of the system were then set and cases were run and analyzed.

2.2 Defining the Models

To run the cases, the model properties must be set. Model properties include the internal ANSYS Fluent solver settings like air and thermal properties, as well as model operating conditions and grid boundary conditions. In fluent launcher under the dimension 3D is selected such that the analysis is carried out in three dimensional. By selecting double precision option and parallel processing options for the calculations would be done faster. Also used to create steady state, enable energy and viscous effects with k-ε model.

The general task page allows setting various generic problem settings, such as those related to the mesh or the solver. The scale mesh dialog box allows you to convert the mesh from various units of measurement to SI or to apply custom scale factors to the individual coordinates of the mesh. Report quality displays various quantities related to the quality of the mesh. In order to check the quality of mesh is used the concept is known as ‘skewness’.

The mesh checking capability in ANSYS Fluent examines various aspects of the mesh, including the mesh topology, periodic boundaries, simplex counters, and (for axis-symmetric cases) node position with respect to x-axis and provides a mesh check report with details about domain extents, statistics related to cell volume and face area.

Solver contains controls relating to solver settings. Type contains the solution methods available for computing a solution of our model. In this pressure based has been used because the flow is incompressible. In velocity formulation the default method i.e., absolute velocity formulation is chosen.

III. NUMERICAL RESULTS AND DISCUSSION

Figure 1 depicts the variation of heat transfer coefficient with heat input and different orientation of grooved wick heat pipe. However, it was observed that at 60^{O} orientations had higher heat transfer coefficient, and lower heat transfer coefficient at 15^{O} orientation. The heat transfer coefficient decreased with decrease in the angle of inclination of the heat pipe.

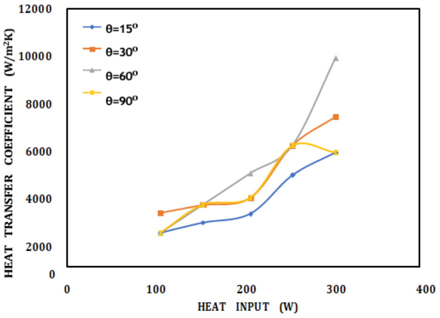

Fig. 1 Variation of heat transfer coefficient with heat input for (m = 0.01kg/s) and orientation of grooved wick heat pipe.

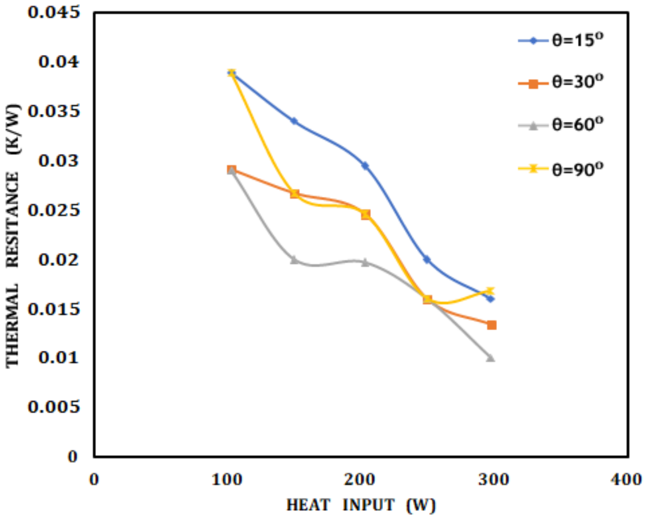

Fig. 2 Variation of thermal resistance with heat input for (m = 0.01kg/sec) and orientation of grooved wick heat pipe.

Figure 2 depicts the variation of thermal resistance with heat input and different orientation of grooved wick heat pipe. However, it was observed that at 60º orientations has lower thermal resistance and 15º orientations has higher thermal resistance. The heat transfer coefficient increased with decreased heat pipe angle.

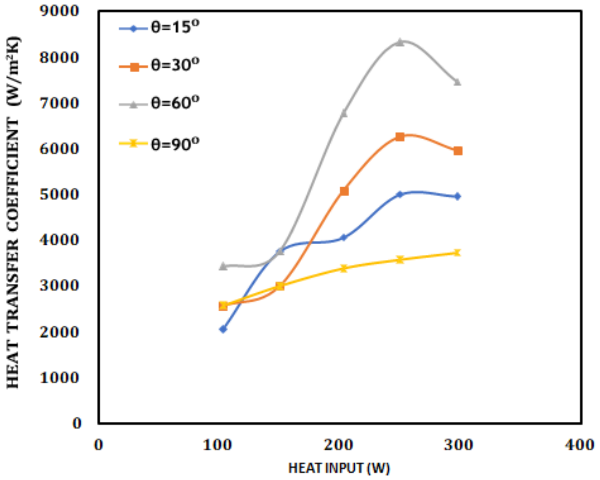

Fig. 3 Variation of heat transfer coefficient with heat input for (m = 0.02kg/s) and orientation of grooved wick heat pipe.

Figure 3 depicts the variation of heat transfer coefficient with heat input and different orientation of grooved wick heat pipe. However, it was perceived that at 60º orientations had high heat transfer coefficient and lower heat transfer coefficient at 90º orientations. The heat transfer coefficient decreased with increased heat pipe angle.

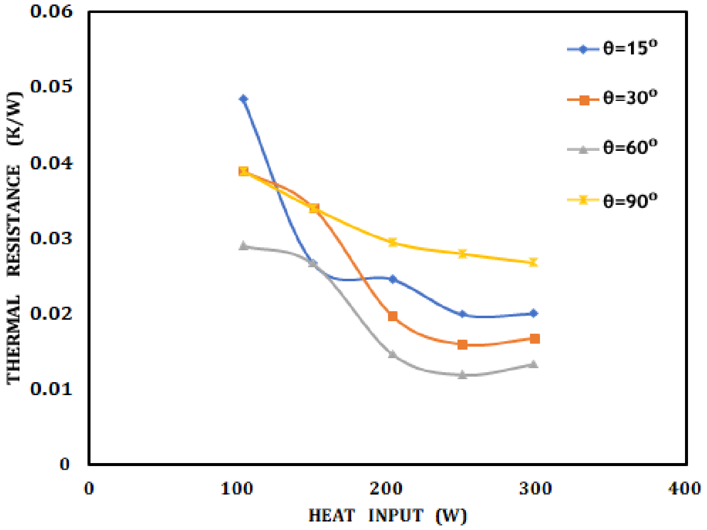

Fig. 4 Variation of thermal resistance with heat input for (m = 0.02kg/s) and orientation of grooved wick heat pipe.

Figure 4 depicts the variation of thermal resistance with heat input and different orientation of grooved wick heat pipe. However, it was examined that at 60º orientations has lower thermal resistance and 90º orientations has higher thermal resistance. The heat transfer coefficient increased with increased heat pipe angle.

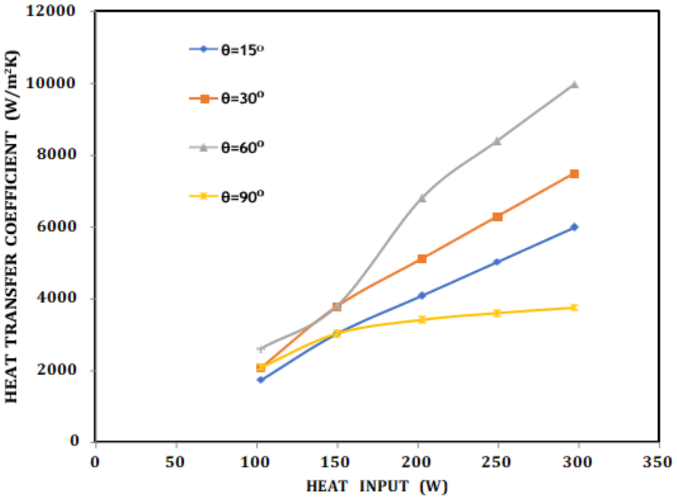

Fig. 5 Variation of heat transfer coefficient with heat input for (m = 0.03kg/s) and orientation of grooved wick heat pipe.

Figure 5 depicts the variation of heat transfer coefficient with heat input and different orientation of grooved wick heat pipe. However, it was observed that at 60° orientation reached high heat transfer coefficient, and less heat transfer coefficient at 90° orientations. The heat transfer coefficient decreased with increased heat pipe orientations.

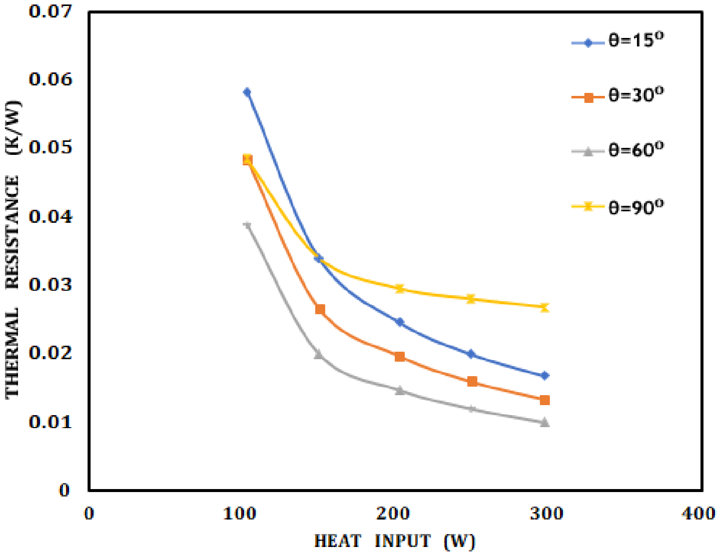

Fig. 6 Variation of thermal resistance with heat input for (m = 0.03kg/s) and orientation of grooved wick heat pipe.

Figure 6 depicts the variation of thermal resistance with heat input and different orientation of grooved wick heat pipe. However, at 60° orientations has lower thermal resistance and 90° orientations has higher thermal resistance. The heat transfer coefficient increased with increased heat pipe angles.

IV. CONCLUSIONS

In this work, numerical investigations of the effect of heat pipe process parameters such as coolant mass flow rate (m), Orientation and heat input (Q) to the grooved wick heat pipe is examined.

- However, it was observed that at 60° orientations had higher heat transfer coefficient, and lower heat transfer coefficient at 15° orientation. The heat transfer coefficient decreased with decrease in the angle of inclination of the heat pipe.
- As the coolant flow rate increases, the heat transfer rate increases as well due to the increased rate of convection.
- It was found that when heat input increases, the heat transfer coefficient rises while thermal resistance was decreased.
- Heat transfer coefficients higher for 90° is 10650 w/m2 at 0.03 kg/sec mass flow rate.

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