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Simulation of Heat Dissipation Behaviour in Grooved Heat Pipe

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Abstract: ***Having high and most effective thermal conductance value heat pipe is widely used for heat transformation. The heat pipe is having unique properties like compact size, light weight and indirect conductance. The heat pipe is used in the cooling of electronic components of computer applications, controlling of temperature in aerospace parts, excess heat recovery in exhaust gases of internal combustion engines. Heat pipes with rectangular cross section can be used for handling large heat transfer sections when weight and space are considered. The working medium that is entrapped in the heat pipe is under phase change from liquid to vapor and vice versa. The vapor condenses in the condenser region by removing heat to the sink and back to the evaporator passing through the porous wick using capillary pumping pressure for re-evaporation. There will be pressure drop in the wick and vapor channel volume. The simple theory of the heat pipe enumerates the capillary pressure in the wick should be more than the sum of the pressure drops in the vapor core and pressure drop in the wick.***

Keywords: thermal conductivity, heat pipe, rectangular pipe, capilliary pump pressure.

I. INTRODUCTION

Heat pipe is designed to transport the heat energy from evaporator end to condenser end with minimum temperature gradient without any external power agent. A typical heat pipe is split into three parts as evaporator section, adiabatic section and condenser section. The overall performance of heat pipe depends on effectiveness of all the three sections.. The heat is inputted in the evaporator end of the heat pipe, the working fluid filled in the evaporator is heated until it gets vaporized. The large latent heat of evaporation in very small temperature difference enables the heat to be transported from one end to the other end and hence the heat pipe will obtain a low thermal resistance. The pressure difference between the evaporator and condenser makes the vapor to flow from evaporator to condenser and releases its latent heat of vaporization to become liquid again. The wicks inside the heat pipe force the liquid back to the evaporator from the condenser. The heat pipes are used in spacecraft, computer systems, solar thermal, cooking, Nuclear power conversion etc. A lot of research has been done to improve the performance of heat pipe. Huang et al.[1] studied on heat pipe coupled with air assisted PCM (PCM/HP-Air), heat pipe coupled with liquid assisted PCM (PCM/HP-Liquid) and found that the heat pipe coupled with liquid cooling exhibit excellent thermal performance for battery module, which is an effective and reliable method with relative longer working time and appropriate temperature. Poplaski et al [2] worked on performance of heat pipe with adding various nano particles such as Al2O3, CuO and TiO2 in the working fluid and observed that the thermal resistance of the heat pipe can me optimized by adding 83%, 79% and 76% of Al2O3, CuO and TiO2, respectively. Many researchers have worked on decreasing the thermal resistance of heat pipe by changing the pipe material, working fluid, wicking structure so that heat energy can be effectivelt transported. Jouhara et al [3] have reviewed on different types of heat pipes, operating temperatures, usability and drawbacks. The mechanism of heat transfer taking place from evaporator to condenser is a complex phenomenon and depends on various factors. Senthilkumar et al [4] have discussed in their paper about the use of response surface methodology (RSM) to optimize the working parameters of the heat pipe with copper nano fluid as working fluid. Kumaresan et al [5] have found that addition of the CuO nanoparticles with working fluid and inclination of the heat pipe to the horizontal enhance the thermal performance of heat pipe. Inclusion of high thermal conductivity particles with working fluid in nano shape to increase the flowability reasonably enhances the heat transfer process. Senthilkumar et al [6] have used the Taguchi method to optimize the working parameters of the heat pipe and found that all the working parameters heat input, tilt angle and flow rate have equal contribution towards the performance of the heat pipe. Jung-Shun Chen et al [7] have examined the cooling effect of Flat plate heat pipe (FPHP) with acetone as working fluid for different angle of inclinations and lengths of the pipe. Experiment showed that increase in pipe length increases the thermal resistance and increase in bending angle of pipe decreases thermal resistance. Maniraman et al [8] have reviewed on affecting parameters on operational characteristics of circular heat pipe. In a heat pipe the main outputs are the thermal resistance and heat transfer capability which can be tuned by choosing suitable working fluid, inclination of the pipe, filling ratio, thermal properties and heat input. Nandy Putra et al [9] have determined the effect of concentrations and the types of nanoparticles in the working fluid (Al_2O_3–water, Al_2O_3–ethylene glycol, TiO_2–water, TiO_2–ethylene glycol and ZnO–ethylene glycol) on the thermal performance of screen mesh wick type heat pipes.

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They found the best performance using Al_2O_3–water nanofluid with 5% volume concentration. Walnuj et al [10] have reviewed the influence of filling ratio, volume fraction of nano practices on thermal performance in different types of heat pipe with different working fluids subjected to different operating conditions. Mozumder et al [11] have conducted a series of experiments with water, methanol and acetone as working fluids and reported that the overall heat transfer coefficient is maximum for acetone with optimized filling ratio. Randeep Singh et al [12] have discussed on the effect of the wick properties including thermal conductivity, pore radius, porosity, and permeability on the heat transfer characteristics of the miniature loop heat pipe (LHP) and observed that copper wicks offer better thermal performance than nickel wicks.The various types of wick structures are shown in fig.1. XueZhihu et al [13] have studied on performance of ammonia as working fluid on closed loop pulsating heat pipe (CLPHP) and found a decreasing trend of thermal resistance by increasing the inclination of CLPHP. Although many people have reported different mechanisms of improving the performance of heat pipe yet more analysis is required to understand the complex phenomenon involved in heat transfer from evaporator to condenser of a heat pipe during the phase change from liquid to vapour . The material of heat pipe plays a major role because strength/weight, thermal conductivity, flexibility in fabrication ease of weld ability, machining ease ability and ductility are to be considered for material selection. The metals like Aluminium, Stainless Steel, Copper, Composite materials, Refractory materials are considered for high temperature heat pipe linings as these materials are corrosion resistant. We have used Ansys for simulation of the heat pipe and conducted series of experiments to find out the effect of heat input on heat transfer coefficient and thermal resistance of heat pipe.

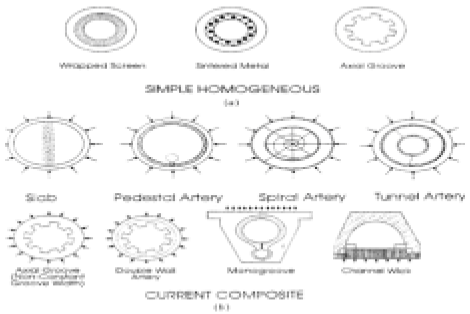

Figure 1. showing various wick structures and capillary wick designs

II. EXPERIMENTAL METHODOLOGY

Heat pipes generally make use of ammonia as working fluid. Here ammonia is used as working fluid. space applications make use of water as working fluid. The other working fluids are methanol and ethanol. The operation ranges of different working fluid are: Ammonia operates in the range of 213-373K, methanol works under the temperature range of 283-403K, ethanol operates under the temperature of 273-403K, water operate at the temperature range of 303-473K. Hence the operating working fluid will be in the range of 20-150^o C. A copper pipe of 565 mm length,15 mm outer and 12 mm inner diameter was chosen for analysis. Using Ansys the temperature, pressure and the velocity profile were studied along the length of pipe. The heat transfer coefficient and thermal resistance for different angles of inclination of heat pipe (15^0,30^0,60^0 and 90^0) and different heat inputs (100W,150W,200W,250W and 300W) were found out and given in the following table.

Table.1: Variation of heat transfer coefficient at different heat input and different inclination of heat pipe.

HEAT INPUT (W)	HEAT TRANSFER COEFFICIENT(W/m^2K) AT INCLINATION ANGLE(degrees)			
	15	30	60	90
100	2541.48	3468.12	2541.44	2495.15
150	3001.63	3789.27	3742.84	3835.6
200	3461.45	4156.38	5083.06	4063.81
250	5033.65	6330.9	6238.28	6284.61
300	6049.78	7486.02	9941.66	5957.12

Table.2: Variation of thermal resistance at different heat input and different inclination of heat pipe.

HEAT INPUT (W)	THERMAL RESISTANCE(K/W) AT INCLINATION ANGLE(degrees)			
	15	30	60	90
100	0.03901	0.029221	0.028929	0.039156
150	0.034042	0.026737	0.01987	0.026737
200	0.029513	0.024545	0.019432	0.024692
250	0.020308	0.016071	0.015925	0.016218
300	0.016218	0.013588	0.009789	0.017094

III. RESULTS AND DISCUSSION

The wicked heat pipe under consideration was analyzed by Ansys. When the working fluid receives the heat from the evaporator, gets converted into vapor and flows towards the condenser. The flow pattern of the phase transition analyzed by Ansys can be seen in fig.2.

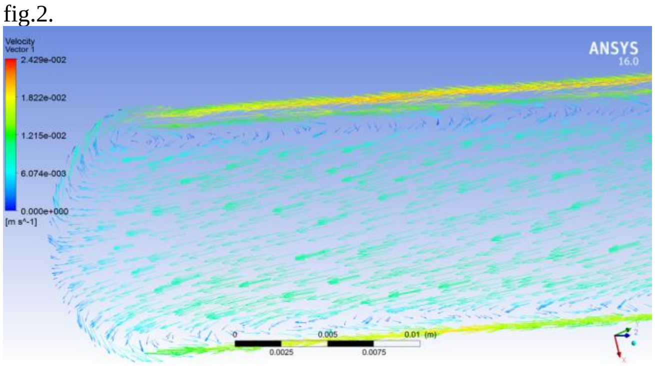

Figure 2: Conversion of phase and flow pattern inside the wicked tube.

To understand the motion characteristics of the vapor while travelling from evaporator to condenser, the velocity profile of the flow was analyzed by Ansys at a heat input of 100Wand shown in fig.3.

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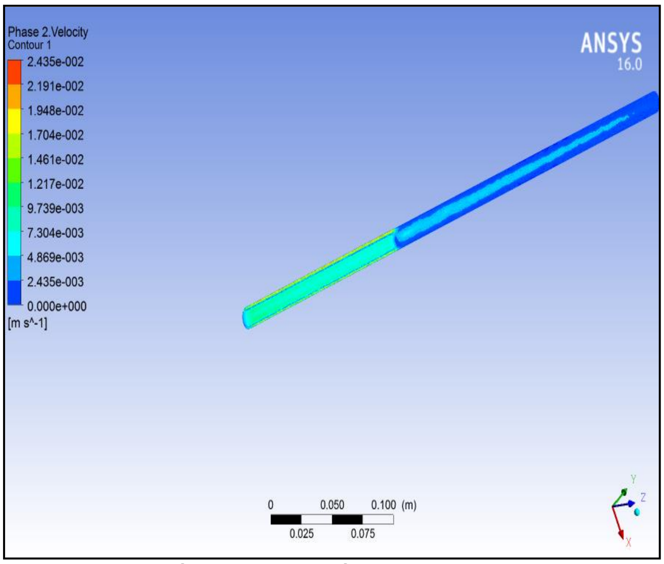

Figure 3: The flow velocity of wicked heat pipe at 100W heat input.

Since it is the pressure difference between evaporator end and compressor end which enables the flow of the working fluid and the pressure difference occurs because of the temperature difference between the ends, the pressure and temperature distribution along the length of the wicked heat pipe was studied at a heat input of 100W and 150W as shown in fig.4,5 and fig.6,7 respectively.

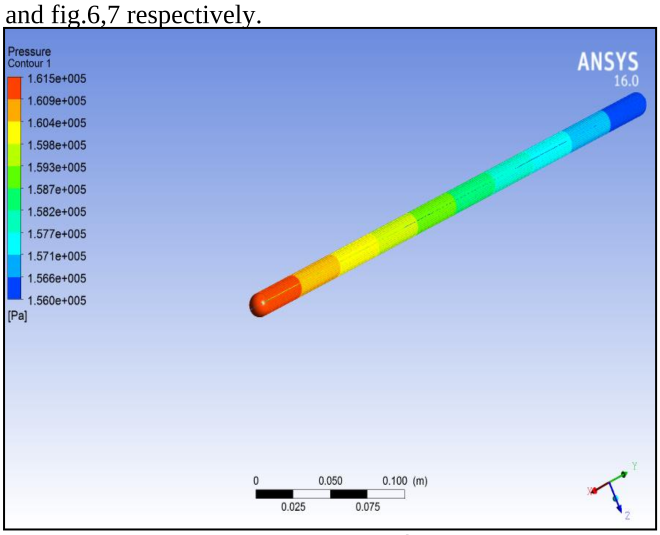

Figure 4: The pressure contour of wicked heat pipe at 100W heat input.

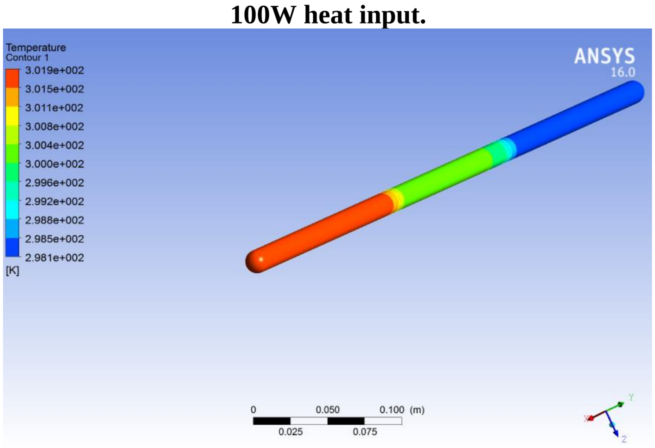

Figure 5: The temperature contour of wicked heat pipe at 100W heat input.

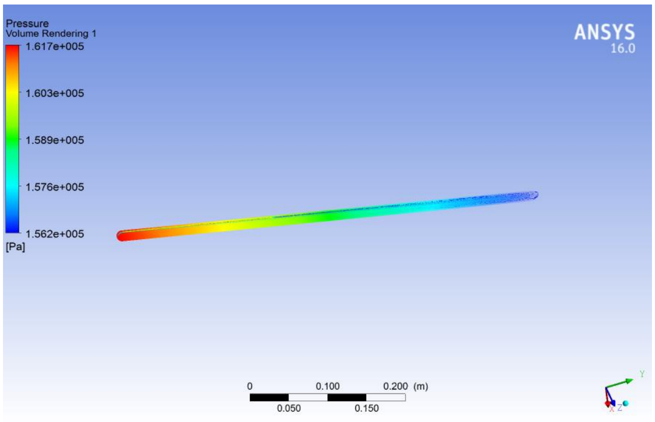

Figure 6: The pressure contour of wicked heat pipe at 150W heat input.

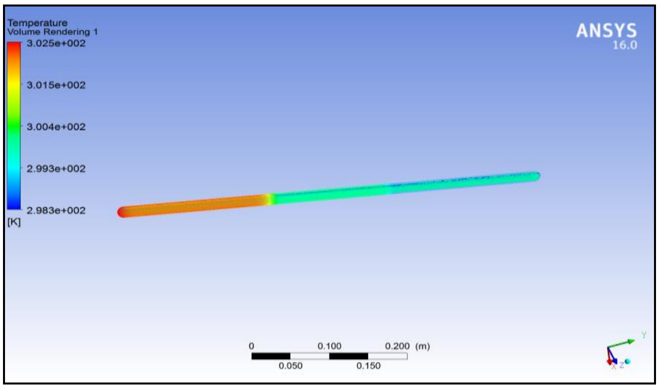

Figure 7: The temperature contour of wicked heat pipe at 150W heat input.

Since the objective of the heat pipe is to transfer the heat effectively with high heat transfer coefficient and low thermal resistance, plots were drawn to find out the effect of both heat input and the angle of inclination of the wicked heat pipe on overall heat transfer coefficient and thermal resistance as shown in fig.8 and fig.9 respectively.

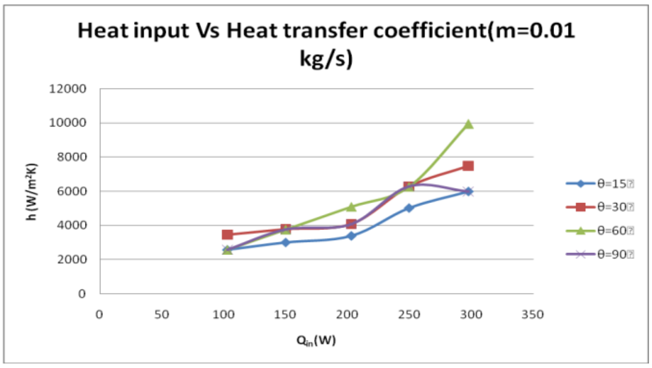

Figure 8: Effect of heat input on heat transfer coefficient at different inclination angles of wicked heat pipe.

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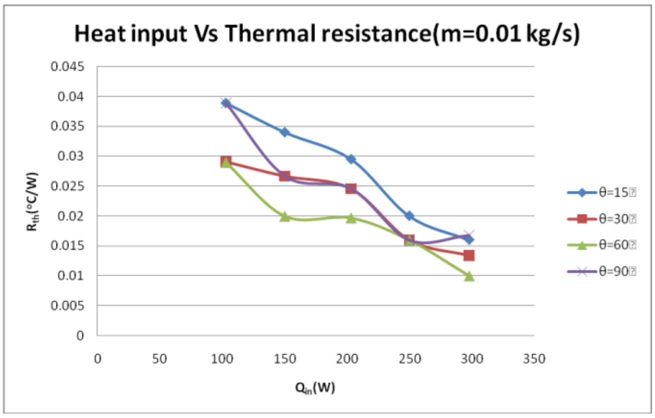

Figure 9: Effect of heat input on thermal resistance at different inclination angles of wicked heat pipe.

Thermal resistance is inversely proportional to increase in inclination angle as shown in fig.9 because gravitational effect is more pronounced but at higher inclination angles there is no time to exchange the heat between the heat pipe and the coolant (water) at condenser section. So thermal resistance decreases up to 60^o and after that it increases.

Thermal resistance decreases with increase in mass flow rate of water. The heat transfer coefficient increases with rise in heat input up to 250W as the thermal resistance decrease and above 250W heat transfer coefficient falls as thermal resistance increases.

From the observation the heat transfer coefficient value is directly proportional to the angle up to 60^o as the thermal resistance decreases and above 60^o heat transfer coefficient decreases as thermal resistance increases.

The heat transfer coefficient is directly proportional to the mass flow rate of water in the condenser section.

IV. CONCLUSION

Having analyzed the wicked heat pipe by Ansys, it is concluded that

- The thermal resistance (R_{th}) is inversely proportional to mass flow rate (m) of coolant in the condenser.
- The decreasing trend of thermal resistance was found to be independent with inclination angle up to 250 W and beyond 250W heat input, the thermal resistance was found to be increasing above 60^0 inclinations.
- The increasing trend of heat transfer coefficient was found to be independent with inclination angle up to 250 W and beyond 250W heat input, the heat transfer coefficient was found to be decreasing above 60^0 inclinations.

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