ISSN: 2348 9510
International Journal Of Core Engineering & Management (IJCEM)
Volume 2, Issue 9, December 2015

SIMULATION AND THERMAL ANALYSIS OF COPPER HEAT PIPE WITH VARIOUS WICK STRUCTURES USING CFX

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ABSTRACT

Heat pipes are the devices used for achieving high heat transfers with the way of their working nature. The applications of heat pipes found in many fields. However, its application to electronic cooling is special. Miniature cylindrical metal powder sintered wick heat pipe (sintered heat pipe) is an ideal component with super-high thermal efficiency for high heat flux electronics cooling. In this paper circular Heat pipe with various Wick geometry 0.4mm,0.6mm,0.8mm and also Sintered, V-Groove, Screen Groove wick shapes is considered, copper is used as a Heat pipe material and nickel-chromium alloy is used as a wick material and water, ethanol, Aqueous ethanol is used as the working fluids. The computer simulation runs made by CFX (the CFD solver program) and the results are analyzed for better working fluid and wick thickness. The results yielded from simulations that water as working fluid and at higher wick thickness are able to enhance the heat pipe performance.

Index Terms*— CFD, *Copper Heat pipe, Heat pipe, CFX Analysis.

I. INTRODUCTION

The first heat-pipe concept can be traced to the Perkins tube. Based on the structure, a heat pipe typically consists of a sealed container charged with a working fluid. A typical heat pipe consists of three sections: an evaporator or heat addition section, an adiabatic section, and a condenser or heat rejection section. For a heat pipe to be functional, the liquid in the evaporator must be sufficient to be vaporized. There are a number of limitations to affect the return of the working fluid. When the pumping pressure produced by the surface tension cannot overcome the summation of the total pressures, the heat transport occurring in the heat pipe reaches a limit known as the capillary limit. There are several other limitations disconnecting the return of the working fluid from the evaporator to the condenser or from the condenser to the evaporator. Among these are the boiling limit, sonic limit, entrainment limit, and viscous limit.

When the heat flux added to the evaporator is sufficiently high, nucleate boiling occurs. The bubble formed in the wick significantly increases the thermal resistance, causing the heat-transfer performance to be significantly reduced. More importantly, when the heat flux is so high, the bubbles block the return of the working fluid and lead to a dry out of the evaporator. The boiling limit plays a key role in a high heat flux heat pipe. When the vapour velocity is high and the cross-sectional area variation of the vapour space in a heat pipe cannot meet the flow condition, chocked flow occurs and the vapour flow rate will not respond with the amount of heat added in the evaporator. This will lead to a sonic limit. The entrainment limit is due to the frictional shear stresses caused by the vapour flow at the vapour–liquid interface. The viscous limit occurs in a low heat flux heat pipe, where the vapour pressure difference in the vapour phase cannot overcome the vapour pressure drop in the vapour phase. From a thermodynamics point of view, the thermal energy added to the evaporator in a functional heat pipe produces the mechanical work to pump the working fluid. No external power is needed for a typical heat pipe. Hence, a heat pipe can transfer a high amount of heat over a relatively long length with a comparatively small temperature differential.

The increasing demand for energy efficiency in domestic appliances (such as a dishwasher, air conditioner, durable drier or fridge/freezer) and industrial systems and devices is the main drive for continuously introducing and/or improving heat recovery systems in these appliances, systems and devices. The heat pipe can be operated from a temperature lower than 4 K to a high temperature up to 3000 K. Because the evaporator and condenser of a heat pipe function independently, the heat pipe can be made into any shape, depending on the design requirement. Due to these unique features, the heat pipe has been widely used in a wide range of applications.

II. OPERATION & SELECTION OF HEAT PIPE

The main regions of the standard heat pipe are shown in Fig. 1. Heat pipe operates on a closed two phase cycle and utilizes the latent heat of vaporization to transfer heat with a `very small temperature gradient. The cross-section of the heat pipe, the Fig1 consists of the container wall, the wick structure and the vapour space.

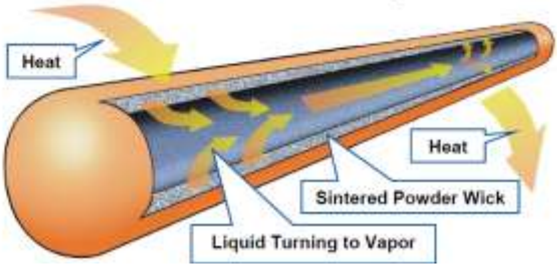

fig. 1 Main parts of a heat pipe

Heat pipe is a high efficiency heat transfer element, depends on the evaporation, condensation and circulation of inside working fluid. The good performance of a heat pipe is due to that the working fluid evaporation of latent heat is generally large, so there needs much working fluid and the circulation flow rate is usually small, and the flow resistance is small, when a heat pipe works. The temperature and pressure inside a heat pipe are nearly at uniform levels through the evaporator to the condenser, so a heat pipe has high heat transfer ability at smaller temperature difference. As per wick structure, the working fluid travels from the condenser section to the evaporator section. The working fluid should be evenly distributed over the evaporator section. In order to provide a proper flow path with low flow resistance, an open porous structure with high permeability is desirable. This is to ensure that the working fluid returns from the condenser to the evaporator.

A. 2.1 How to select a heat pipe

1) Investigate and determine the following operational parameters:
   a. Heat load and geometry of the heat source.
   b. Possible heat sink location, the distance and orientation relative to the heat source.
   c. Temperature profile of heat source, heat sink and ambient
   d. Environmental condition (such as existence of corrosive gas)
2) Select the pipe material, wick structure, and working fluid.
   a. Determine the working fluid appropriate for your application.
   b. Select pipe material compatible to the working fluid
   c. Select wick structure for the operating orientation
   d. Decide on the protective coating.
3) Determine the length, size, and shape of the heat pipe.

III. CFD MODELLING

A. Specifications of work

Heat pipe material	:	Copper
Wick material	:	Nickel-Chromium alloy
Wick Thickness	:	0.4mm, 0.6mm, 0.8mm.
Types of Wicks	:	Sintered, V-Groove,ScreenCovergroove

Length of Heat pipe : 190 mm
Thickness of a Heat pipe : 2 mm
Outer diameter of a Heat pipe : 12 mm

B. Design files

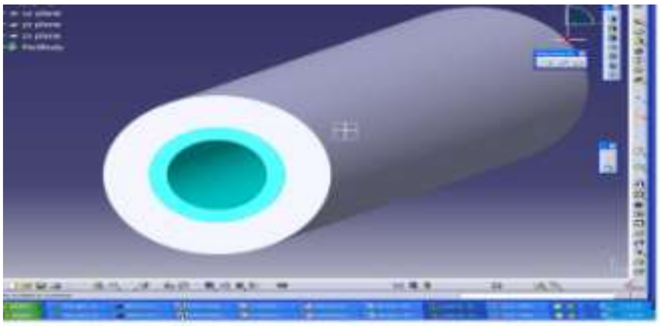

fig. 2 Sintered wick Heat pipe

fig above shows that the modelling of a Sintered Heat pipe with wick material having inner walls of the heat pipe with required wick dimensions.

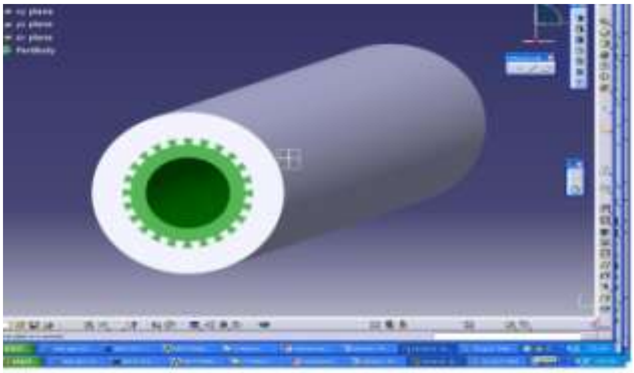

fig. 3 Screen groove wick Heat pipe

Fig above shows that the modelling of a Screen Groove wick heat pipe with wick material having inner walls of the heat pipe with required wick dimensions.

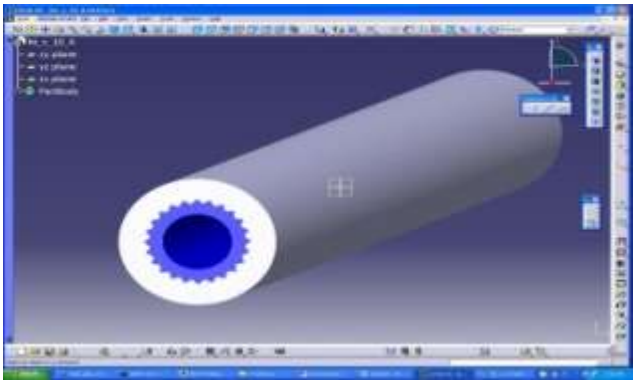

fig 4 V-groove Heat pipe

Fig above shows that the modelling of a V-Groove wick heat pipe with wick material having inner walls of the heat pipe with required wick dimensions.

C. Input data

Water Velocity = 0.1 m/s
Water inlet Temperature = 303 K
Evaporator Section Temperature = 360 K
Condenser Section Temperature = 290 K

D. Contours of Heat pipe

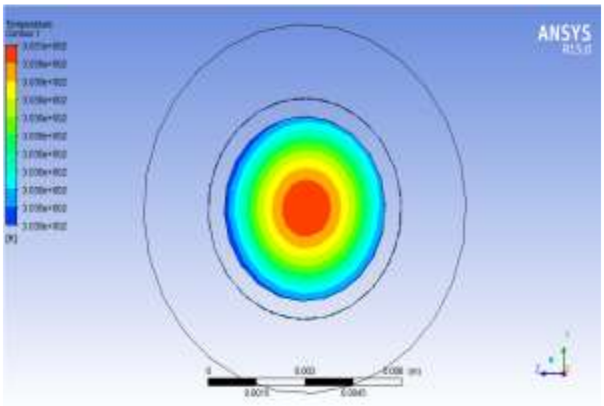

Fig 5 Contours of a Heat pipe with water as a working fluid

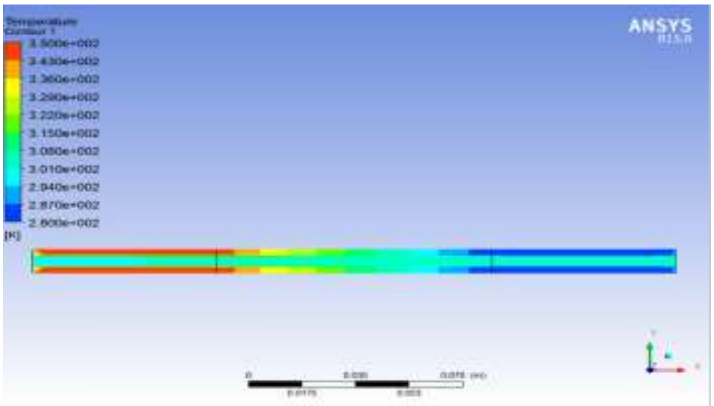

Fig 6 Contours of a Heat pipe with ethanol as a working fluid

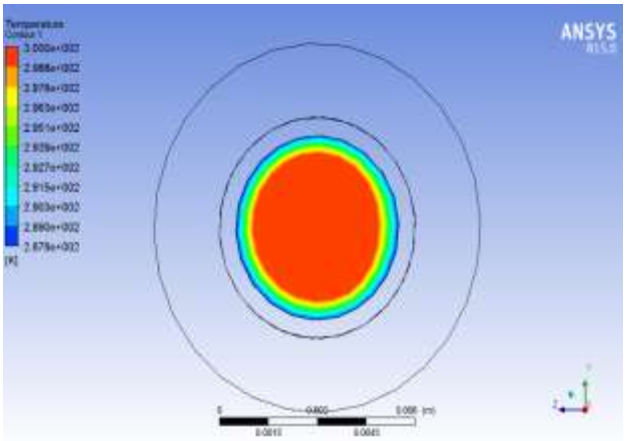

Fig 7 Contours of a Heat pipe with aqueous ethanol as a working fluid

IV. RESULTS AND DISCUSSION

Finally for convenient comparison table 1 is given that reports average of outlet flow temperature and temperature difference (ΔT). Inlet flow temperature is 360 K for all of them.

Table.1. Outlet temperatures and temperature Gradients for 0.4 mm wick for all shapes of wicks

Wick thickness	Working fluid	Type of wick	Tout(K)	ΔT(K)
0.4 mm	Water	Sintered	309.16	50.84
0.4 mm	Ethanol	Sintered	309.51	50.49
0.4 mm	Aqueous Ethanol	Sintered	310.81	49.19
0.4 mm	Water	V-Groove	308.62	51.38

0.4 mm	Ethanol	V-Groove	308.97	51.03
0.4 mm	Aqueous Ethanol	V-Groove	309.02	50.98
0.4 mm	Water	Screen groove	307.80	52.20
0.4 mm	Ethanol	Screen groove	308.01	51.99
0.4 mm	Aqueous Ethanol	Screen groove	308.82	51.18

Table.2. Outlet temperatures and temperature Gradients for 0.6 mm wick for all shapes of wicks

Wick Thickness	Working fluid	Type of wick	Tout(K)	ΔT(K)
0.6 mm	Water	Sintered	307.73	52.27
0.6 mm	Ethanol	Sintered	308.94	51.06
0.6 mm	Aqueous Ethanol	Sintered	308.09	51.91
0.6 mm	Water	V-Groove	305.82	54.18
0.6 mm	Ethanol	V-Groove	306.52	53.48
0.6 mm	Aqueous Ethanol	V-Groove	306.96	53.04
0.6 mm	Water	Screen groove	304.38	55.62
0.6 mm	Ethanol	Screen groove	304.98	55.02
0.6 mm	Aqueous Ethanol	Screen groove	304.90	55.10

Table.3. Outlet temperatures and temperature Gradients for 0.8 mm wick for all shapes of wicks

Wick thickness	Working fluid	Type of wick	Tout(K)	ΔT(K)
0.8 mm	Water	Sintered	304.80	55.20
0.8 mm	Ethanol	Sintered	305.64	54.36
0.8 mm	Aqueous Ethanol	Sintered	306.01	53.99
0.8 mm	Water	V-Groove	303.87	56.13
0.8 mm	Ethanol	V-Groove	303.95	56.05
0.8 mm	Aqueous Ethanol	V-Groove	303.98	56.02
0.8 mm	Water	Screen groove	302.05	57.95
0.8 mm	Ethanol	Screen groove	304.28	55.72
0.8 mm	Aqueous Ethanol	Screen groove	305.21	54.79

A. Graphs

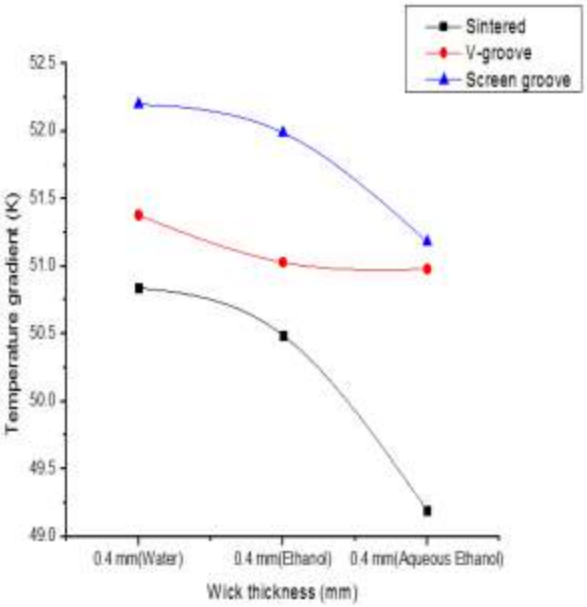

Fig.8 variation of working fluids with temperature gradient for 0.4 mm wicks

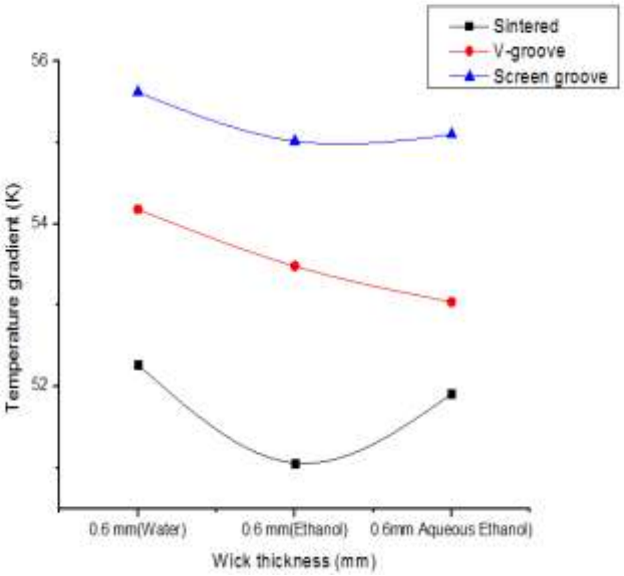

Fig.9 variation of working fluids with temperature gradient for 0.6 mm wicks

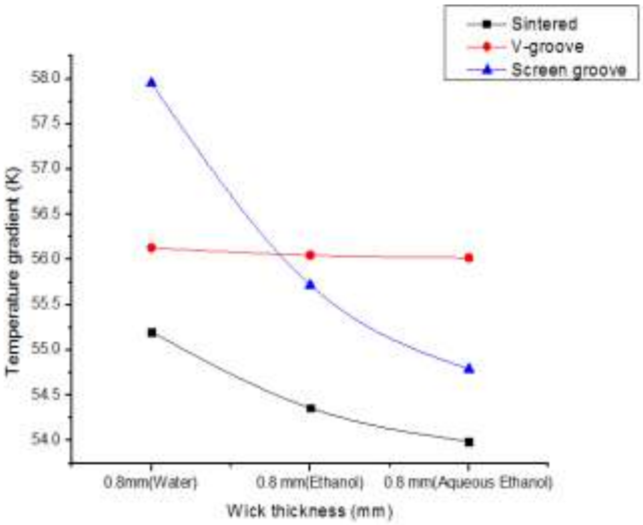

Fig.10 variation of working fluids with temperature gradient for 0.8 mm wicks

V. CONCLUSIONS

From the above results and discussions it is clear that water has the highest temperature gradient and high heat transfer coefficient among the three working fluids. As the wick thickness increases, heat transfer rate increases considerably. Screen groove structured wick performance seems to be better over other wick structures. It is concluded that the heat pipe with water as a working fluid is advantageous as it is readily available and cheap in cost.

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