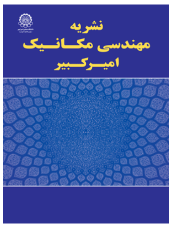

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Numerical Investigation of Hybrid Wick Structure Effect on Thermal Performance of a Thin Flat Heat Pipe

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ABSTRACT: Due to the volume and mass limits of the small electronic devices, thin flat heat pipes are an ideal solution for the efficient transfer and dissipation of heat. The performance of thin heat pipes is heavily dependent on wick structure characteristics. In this research, the thermal performance of thin flat heat pipes with hybrid and grooved wick for different heat inputs were studied numerically, and their heat transfer characteristics were compared. The trends of various parameters such as wall temperature, maximum axial velocity, mass transfer at the liquid-vapor interface, system pressure, and thermal resistance on the thermal performance of the thin flat heat pipe with hybrid and groove wicks were analyzed. The numerical simulation has been done using a two-dimensional unsteady incompressible laminar flow. Results indicated that the evaporation section temperature of hybrid wick thin flat heat pipe is significantly lower than the corresponding value of grooves heat pipe. It was also observed that with increasing heat input, the thermal resistance of hybrid wick thin flat heat pipe decreased and it has excellent performance compared to the grooved wick. For heat fluxes of 10, 20, and 30 W, the performance of the thin flat heat pipe with hybrid wick compared to grooved wick is improved by 3.59%, 20.38%, and 28.57%, respectively. Therefore, the thermal performance improvement of the thin flat heat pipe with the hybrid wick was more significant. This improvement is more considerable for higher heat fluxes..

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1- Introduction

Because of the increasing heat flux requirements and thermal limits in many industrial processes, there has been notable interest in using heat pipes for thermal management [1]. Heat pipes have been shown to be among the most efficient passive cooling solutions for electronic devices, for example, in Central Process Unit (CPU) [2], Microelectromechanical Systems (MEMS) [3], spacecraft [4], satellite [5], and so on. A nearly uniform temperature is maintained throughout the device by using phase change in a heat pipe.

Due to the volume and mass limits of the small electronic devices, thin flat heat pipes are an ideal solution for the efficient transfer and dissipation of heat. However, unlike traditional heat pipes, the performance of thin heat pipes is heavily dependent on wick structure characteristics [6]. The wick structure is the key component of a heat pipe because it provides capillary force and flow paths for the circulation of the working fluid. The two most frequent wick forms utilized inside the wick heat pipe are homogeneous wick and hybrid wick. Each wick has its own characteristics. For example, a grooved wick has high permeability and low capillary pressure, while sintered wick has large capillary pressure and low permeability [7]. However, large capillary pressure and high permeability cannot be satisfied by a homogeneous wick. Thus, it is necessary to investigate the hybrid wick structure.

In the present study, the thermal performance of Thin Flat Heat Pipes (TFHP) with hybrid and groove wick structures for different heat inputs are studied numerically, and their heat transfer characteristics are compared. The trends of various parameters such as wall temperature, maximum axial velocity, mass transfer at the liquid-vapor interface, system pressure, and thermal resistance on the thermal performance of the TFHPs with hybrid and groove wick structures are analyzed.

2- Model Description

The heat pipe dimensions were chosen to correspond with an actual heat pipe [8]. As illustrated in Fig. 1, the overall dimensions of the TFHP are 225×10.5×4.5 mm3, and the lengths of the evaporator, adiabatic, and condenser sections are 30, 100, and 95 mm, respectively. Since the external applied heating and cooling are symmetric, the 3-D heat pipe can be simplified as a 2-D model, a cross section was selected in the present study as shown by dashed lines in Fig.1. The detailed 2-D model and boundary conditions are detailed in Fig. 2 and Table 1.

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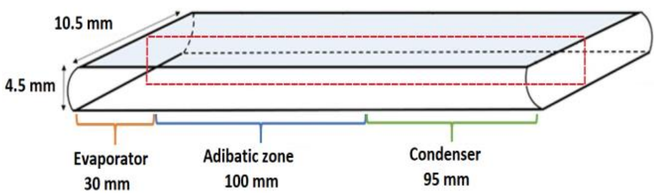

Fig. 1. Dimensions of thin flat heat pipe investigated

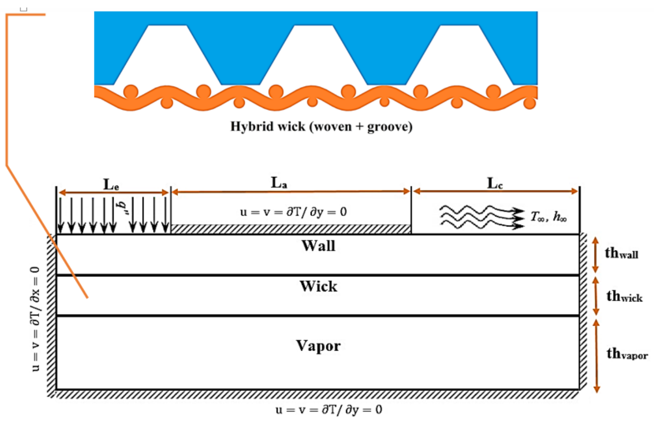

Fig. 2. Detailed boundary conditions of the 2-D model

Table 1. Detailed dimensions of the 2-D model

Parameter	Value
Evaporator length (L_e)	30 mm
Adiabatic length (L_a)	100 mm
Condenser length (L_c)	95 mm
Wall thickness (th_{wall})	0.8 mm
Wick thickness (th_{wick})	0.4 mm
Vapor thickness (th_{vapor})	3.3 mm

The heat pipe geometry consists of three different regions: Wall, Wick, and Vapor domains. The wall and wick are made of copper and the working fluid is water. The hybrid wick consists of three layers: two layers of woven mesh and the outer layer of the grooved structure. The hybrid wicks consist of two different structures and cannot be treated homogeneous, therefore, the effective thermal and viscous properties of hybrid wicks were first calculated and the entire wick structure was then simplified as a uniform porous media.

The thermophysical properties of the wall, wick, and vapor core are listed in Table 2. The properties for the hybrid mesh were calculated according to Refs. [9, 10]. The heat pipe is simulated with different heat inputs ranging from 2.5 W to 30 W. The coolant water temperature and the heat transfer coefficient on the condenser side are 21°C and 1300 W/m2K, respectively. The initial temperature all through the heat pipe is 21°C and the vapor is assumed to be saturated.

Table 2. Detailed thermal properties

Zone	Properties	Value	Units
Wall	Specific Heat	381	J / kg.K
	Density	8978	kg / m^3
	Thermal Conductivity	387.6	W / m.K
Wick	Specific Heat	4200	J / kg.K
	Density	$M_{Wick} / LW\delta$	kg / m^3
	Dynamic Viscosity	8×10^{-4}	$N.s / m^2$
	Thermal Conductivity	1.2	W / m.K
	Permeability	1.1×10^{-9}	m^2
	Porosity	0.718	-
Vapor	Specific Heat	1861.54	J / kg.K
	Density	P_{op} / RT	kg / m^3
	Thermal Conductivity	0.0189	W / m.K
	Dynamic Viscosity	8.4×10^{-6}	$N.s / m^2$
	Latent heat	2.33×10^{6}	J / kg

3- Results and Discussion

Fig. 3 illustrates the wall temperature distribution of hybrid and grooves heat pipe for different heat inputs in a steady state. As shown, the condensation section temperature stays the same for hybrid and grooves heat pipe while the evaporation section temperature of the hybrid wick heat pipe is significantly lower than the corresponding value of grooves heat pipe. Also, the effectiveness of hybrid wick, in terms of the temperature difference between the condenser and evaporator, increases as heat flux increases.

Thermal resistances of hybrid and grooves heat pipe is depicted in Fig. 4 for different heat inputs. It was also observed that with increasing heat input, the thermal resistance of hybrid wick TFHP decreased and it has excellent performance compared to the grooved wick. For heat fluxes of 10, 20, and 30 W, the performance of the TFHP with hybrid wick compared to grooved wick is improved by 3.59%, 20.38%, and 28.57%, respectively. Therefore, the thermal performance improvement of the TFHP with the hybrid wick was more significant.

4- Conclusions

The thermal performance of TFHP with hybrid and grooved wick for different heat inputs were studied numerically, and their heat transfer characteristics were compared to each other. The results show that the use of a hybrid wick structure significantly

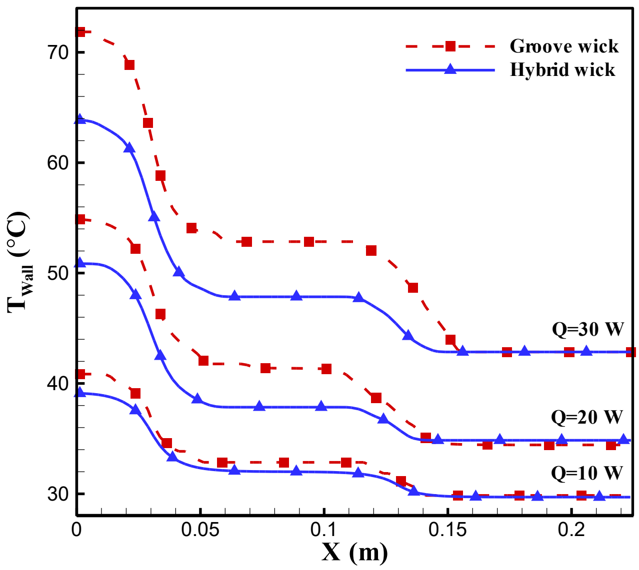

Fig. 3. Steady state wall temperature distribution of hybrid and grooves heat pipe for different heat inputs

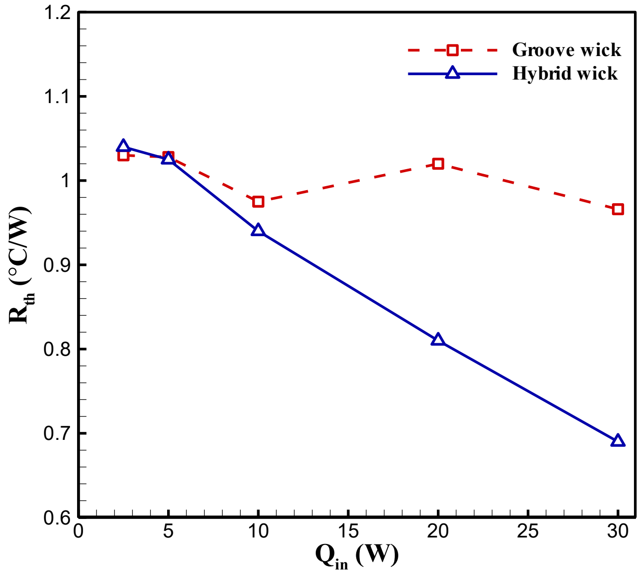

Fig. 4. Thermal resistances of hybrid and grooves heat pipe

improves the evaporation section temperature and thermal resistance. This improvement is more considerable for higher heat fluxes.

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