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Research Paper

Performance of cylindrical and flattened heat pipes at various inclinations including repeatability in anti-gravity – A comparative study

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HIGHLIGHTS

- Heat transfer of cylindrical and flattened heat pipes are compared.
- Influence of tilt angle, mesh size of wick and cross section of heat pipe studied.
- Reliable operation of heat pipe in anti-gravity confirmed with repeated tests.

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ABSTRACT

A comparative study of cylindrical and flattened heat pipes having different screen mesh size wicks is conducted at various inclinations (−90° to +90°) for a heat load range of 10–60 W. The effect of flattening of heat pipes having same screen mesh wick at various inclinations are also analysed. Anti-gravity (−90°) tests are also repeated at different time intervals to analyze the reliability of these heat pipes if they have to remain idle for a certain period. Experiment results show that the thermal performance of the heat pipes are influenced by inclination angle, mesh size of the wick, cross section of the heat pipe and heat input. The inclination at which the maximum heat transfer occurs is not the same for three heat pipes tested. The lowermost thermal resistance witnessed is 0.46 K/W, for cylindrical heat pipe, at an inclination of −45° for an applied heat input of 60 W. The maximum evaporator and condenser heat transfer coefficient values observed are 3876 W/m^2 K and 1698 W/m^2 K respectively. The anti-gravity repeatability tests shows that these heat pipe works well even after some idle period and the variation in evaporator temperature is found to be less than ±7.5%.

1. Introduction

The need to improve the efficiency of heat transfer has been the subject of much investigation across a broad scope of engineering fields, from aerospace to waste heat recovery in renewable systems and particularly in electronics cooling. The devices we carry today have increasing capabilities on smaller devices, consider; tablets, smart phones and other wearable technology. The additional operations in combination with smaller circuits results in devices overheating. Therefore, a sophisticated method of thermal management is required. Similarly, cooling of heat-producing components within a laptop computer can be critical to avoid excessive amounts of heat build-up which can adversely affect the performance of a processor and other electronic components. So an efficient cooling method is required to increase the reliability of electronic devices along with satisfying compact packaging requirements. Many modern technologies utilise heat pipes as an efficient mode of heat transfer, this mode of thermal management will be focus of this paper.

As heat pipes do not have any moving parts they have gained a reputation of exceptional reliability with the additional benefit of being an entirely passive system. Heat pipes works on the principles of boiling and condensation utilizing latent heat for their operation. They allow high heat transfer rates over considerable distance, with minimal temperature drops, and exceptional flexibility. Additionally, heat pipes are relatively easy to construct and control without a need for external pumping. Nowadays

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Nomenclature

FR	filling ratio (%)
DC	direct current
GI	galvanized iron
R_t	thermal resistance of heat pipe (K/W)
V	voltage (V)
I	current (A)
h_e	heat transfer coefficient at evaporator (W/m^2 K)
h_c	heat transfer coefficient at condenser (W/m^2 K)
T	temperature (°C)
Q_A	applied heat load (W)
Q_R	heat rejected at condenser (W)
q	heat flux (W/m^2)
A	area (m^2)
L	length of heat pipe from evaporator to condenser (m)
K_{eff}	effective thermal conductivity of heat pipe (W/m K)
m	mass flow rate of air (kg/s)
c	specific heat of air (J/kg K)
d_o	outer diameter of the heat pipe (m)

Greek symbols

Δ	change

Subscripts

e	evaporator
c	condenser
ve	vapour at evaporator
vc	vapour at condenser
c/s	cross sectional

flattened heat pipes are preferred instead of cylindrical heat pipes in compact electronic devices because they increase heat transfer area and keep the devices compact. Many researchers have experimentally worked with both cylindrical and flattened heat pipes having different wick structures. Researchers have mainly compared the heat transfer of cylindrical heat pipes using water and nanofluid at various dimensions of heat pipe, heat loads, wick structures, inclination angles, filling ratios (FR) and volume fraction of nanoparticles.

Ramachandran et al. [1] experimentally studied the heat transfer performance of a cylindrical heat pipe having mesh wick (100 mesh size) in horizontal orientation with a hybrid nanofluid containing Al_2O_3 and CuO nanoparticles in distilled water. Results showed a decrease of 44.25% in thermal resistance when distilled water is replaced with nanofluid. Asirvatham et al. [2] used a cylindrical heat pipe having screen mesh wick to determine the various limitations of the heat pipe using distilled water and nanofluid of silver nanoparticles. The experiments were performed in horizontal orientation for heat inputs from 20 to 100 W. The experimental results showed an increase in capillary limit which also indicated an increase in the working range of heat pipe with the use of nanofluid. Asirvatham et al. [3] analysed the thermal performance of a horizontal heat pipe having 100 mesh wick using distilled water and nanofluid. A reduction of 76.2% was observed in thermal resistance with nanofluid when heat pipe operated in horizontal orientation. Kumaresan et al. [4] experimentally compared the heat transfer performance of a cylindrical heat pipe using screen mesh and sintered wicks by conducting tests in different inclinations, filling ratios and heat inputs. The working fluids used were distilled water and CuO nanofluid. Results showed a lowest evaporator temperature at inclination angles of 45° and 60° for sintered and screen mesh wicks respectively for a nanofluid concentration of 1.0 wt.%. Kumaresan et al. [5] studied the effect of nanoparticles on the thermal performance of a cylindrical heat pipe having sintered wick at various tilt angles for different heat inputs and concentrations of nanoparticles. Results indicated that inclination angle influenced the heat transfer and 45° tilt angle showed the maximum heat transfer with a reduction of 66.1% in thermal resistance. Solomon et al. [6] conducted a numerical analysis on a cylindrical heat pipe having screen mesh wick in horizontal orientation using distilled water and nanofluid as working fluids. Results showed that nanofluid increased the heat transfer with reduction in evaporator wall temperature. Loh et al. [7] compared the thermal performance of cylindrical heat pipes having different wick structures at various tilt angles. Experimental results suggested that the sintered wicks holds good for anti-gravity orientations and grooved heat pipe for gravity assisted orientations. Senthilkumar et al. [8] performed a study with experiments on a cylinder-shaped heat pipe using distilled water and copper nanofluid as working fluids at various inclinations of the heat pipe. Experiment results showed an increase in heat transfer with nanofluid and the effect of inclination on heat transfer was not explored in detail. Yousefi et al. [9] studied the influence of inclination angle of a heat pipe used for CPU cooling using nanofluids. The results showed that inclination angle is important parameter influencing CPU temperature.

Tao et al. [10] analysed the working of a flattened heat pipes having diverse thicknesses of 3.5 mm, 3 mm, 2.5 mm, and 2 mm. The results showed that the decrease in thickness of flattened heat pipe led to increase in thermal resistance. Jiang et al. [11] used a flattened heat pipe fabricated from a cylindrical heat pipe having a composite wick of grooved sintered wick for heat transfer study. The test results were compared with a grooved wick and sintered wick flattened heat pipe. Results showed that the thermal resistance of heat pipe with composite wick was in between grooved wick and sintered wick flattened heat pipes. Li et al. [12] studied the influence of flattened thickness on the thermal performance of a flattened heat pipe having sintered wick using experiments and mathematical model. The results showed a decreasing trend in heat transfer when thickness of the flattened heat pipe was reduced. Lin and Wong [13] experimentally investigated the heat transfer phenomenon of a grooved and sintered flattened heat pipes using water as the operating fluid. A reduction in heat transfer was observed in flattened heat pipe which was attributed to liquid clogging at condenser region and interfacial shear between vapour and liquid in sintered and grooved heat pipes respectively. Li et al. [14] studied the heat transfer phenomenon in a thin flattened heat pipe having composite wick structures and examined the limits of the heat pipe. The maximum heat transfer limit was found to be less than 14 W at optimum filling ratios.

A few researchers [15–19] have also worked with other heat pipes in different inclinations and wick structures to scrutinize the thermal behaviour of heat pipes. Many practical applications such as aircraft electronics, military vehicles, laptop etc come up with situations like change in orientation of heat pipe during their operation. In such situations the reliability of heat pipe cooling is very important because there is a possibility of decrease in performance due to fast dry out when heat pipe is operated in anti-gravity orientations. In such cases, the capillary driven heat pipes solely depends on the capillary action of the heat pipe to supply