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Thermal characteristics studies on sintered wick heat pipe using CuO and Al_2O_3 nanofluids

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ABSTRACT

In the present experimental work, the thermal characteristics of cylindrical sintered wick heat pipe are investigated using CuO and Al_2O_3 nanofluids. The size and morphology of the nanoparticles are maintained as constant to analyze the distinctive performances of nanoparticles on the thermal enhancement of heat pipe. The effect of inclination angle and heat input on the thermal performance of heat pipe is also studied. The addition of nanoparticles has a notable influence in surface temperature of heat pipe and it is gradually reduced with increasing concentration. The reduction for 0.5 wt.%, 1.0 wt.% and 1.5 wt.% of CuO nanofluids are 2.1 °C, 5.9 °C and 4.7 °C respectively, whereas for the same concentrations Al_2O_3 nanofluids obtain only 0.9 °C, 3.6 °C and 5.3 °C respectively compared with DI water at horizontal position. Thermal resistance of heat pipe is dramatically reduced with increasing heat flux at low heat input and the reduction is diminished for peak loads. The optimum performance is attained for both CuO and Al_2O_3 nanofluids at 45° inclination angle. In contrast, the optimum concentration is varied i.e., 1.0 wt.% for CuO and 1.5 wt.% for Al_2O_3 nanofluids. The evaporation and condensation HTC is increases about 32.99% and 24.59% respectively for CuO and Al_2O_3 nanofluids at 45°.

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1. Introduction

Thermal management in the electronic devices is one of the foremost issue, most of the failures in the electronic circuits occurred because of its high operating temperature. Few conventional cooling methods are existed, but having poor heat dissipation efficiency and it leads to increase in the component temperature. In contrast with the past, heat pipes are widely used for high heat flux operation because of its excellent heat removal capacity. Furthermore, it can be operated effectively even at small/confined spaces due to its compactness. Some authors has already conducted the experimental [1–9,12,13] and numerical [10,11,14] study on the enhancement in thermal performance of heat pipe by varying its parameters such as heat flux, working fluid, operating pressure and temperature, fluid filling ratio, and inclination angle.

Liu and Li [3] performed an experiment using cylindrical micro grooved heat pipe with CNT dispersed in DI water under different operating temperatures viz. 40 °C, 50 °C and 60 °C. The authors have indicated that the performance of heat pipe has increased with the addition of carbon nanotubes in base fluid. Hassan et al. [4] experimentally investigated in a circular heat pipe made up of brass tube with 1.0 and 3.0 vol.% of alumina/DI water nanofluid. The authors concluded that the temperature difference between the evaporator and condenser end reduces with increase in the heat load. Han and Rhi [5] investigated the thermal performance of grooved heat pipe with Ag and Al_2O_3 suspended hybrid nanofluid with different concentrations. The graph plotted with the temperature distribution of heat pipe with 50 W and 200 W showed the addition of pure and hybrid nanofluids in heat pipes effectively operates at high temperature compared with DI water.

Kumar et al. [7] conducted an experimental study in a mesh wick heat pipe to evaluate its thermal characteristics. The experimental results were validated with that of numerical study. The authors found that the heat transport rate of heat pipe was increased with the tilt angle from 15° to 25° and inclination of heat pipe after the value led deterioration in the heat transport rate. Liu et al. [8] experimentally investigated the thermal performance of micro-grooved heat pipe using nanofluids. The authors used CuO, Cu and SiO nanoparticles with the diameter of 50, 40 and 20 nm respectively. The results show that addition of Cu and CuO nanoparticles improved the heat pipe performance whereas SiO nanoparticles weakened it. It was because of coating layers were

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Nomenclature

A	area (m^2)
D	outer diameter (mm)
d	diameter of copper wire
h	heat transfer coefficient ($W/m^2 °C$)
I	current (A)
k	thermal conductivity (W/m K), permeability (cm^2)
N	number, mesh number (mesh/in.)
Q	heat supplied (W)
q	heat flux (kW/m^2)
R	thermal resistance (°C/W)
T	temperature (°C)
V	voltage (V)
ΔT	temperature difference (°C)

Subscripts

bf	base fluid
c	condenser
e	evaporator
hp	heat pipe
nf	nanofluid
s	surface
t	thermocouple
th	thermal
v	vapor
vs	vapor-surface
w	water

Greek symbols

θ	tilt angle (°)
ε	porosity
μ	dynamic viscosity ($N s/m^2$)
ρ	density (kg/m^3)
ω	weight fraction (wt.%)
Δ	increment

formed by the nanoparticles over the wick structure as well as the different morphology of nanoparticles. Asirvatham et al. [9] found that the thermal resistance of mesh wick heat pipe was reduced about 76.2% for 0.009 vol.% concentration of Ag nanofluid compared with its base fluid. Hassan and Harmand [10] conducted a three dimensional numerical study on flat heat pipe. They concluded the pressure difference increased with heat input/heat transfer coefficient of the cooling fluid. The same authors [11] presented an experimental and numerical study on the flat heat pipe and found that the porosity of powder + mesh wick was more efficient than mesh and powder wicks in electronic cooling.

Wang et al. [12] experimentally investigated the operation characteristics of cylindrical micro-grooved heat pipe using aqueous CuO nanofluid. They observed that the total thermal resistance of heat pipe was reduced by 50% and the heat transport capacity was increased by 40% due to the addition of CuO nanoparticles in DI water. Shafahi et al. [15] numerically analyzed the thermal performance of heat pipe by varying the nanoparticles viz. CuO, Al_2O_3 and TiO_2 and the size of nanoparticles were 10 nm, 20 nm and 40 nm respectively. The authors concluded that the size variation in nanoparticles affected the thermal performance of heat pipe. Teng et al. [16] pointed out that the thermal efficiency of mesh wick heat pipe improved with the addition of 1 wt.% of Al_2O_3nanoparticles. More over the suspension of nanoparticles reduced the charged amount of working fluid from 60% to 20%. Do et al. [17] employed the dilute dispersion of Al_2O_3nanoparticles with the volume fraction of 1.0% and 3.0% into the water. The solution was used to study the thermal characteristics of screen mesh wick heat pipe by varying heat input. They obtained a maximum reduction of 40% in thermal resistance with 3.0 vol.% of Al_2O_3-water nanofluid. Naphon et al. [18] experimentally studied the thermal efficiency of cylindrical heat pipe with R11-refrigerant based TiO2 nanoparticles. The authors also investigated the effect of charged amount of working fluid viz. 25%, 37.5%, 50% and 66% respectively. They observed the heat pipe with 0.1 vol.% of TiO_2 nanoparticles recorded the maximum efficiency i.e., 1.40 times higher than that of pure refrigerant for the optimum filling volume of 50%. Liu et al. [19] conducted a pool boiling heat transfer study on a plain copper heated surface using CuO and SiO_2 nanoparticles suspended in water and alcohol with and without surfactants. The authors reported the nanoparticles dispersion in the base fluids without surfactants produced a steady pool boiling phenomenon with no agglutination. A thin nanoparticles sorption layer was also formed over the heating surfaces which increased the critical heat flux. Kumaresan et al. [20] compared the thermal performance of sintered and mesh wick heat pipes using CuO nanofluids. The results show that the thermal resistance of sintered wick heat pipe is lower than that of mesh wicks irrespective of heat input and inclination angle. The maximum reduction obtained in the thermal resistance is of 14.20% compared with the mesh wick heat pipes. The authors stated that the porosity of sintered wick is high and it enhances the nucleate boiling in the evaporator section of heat pipe. Choi et al. [21] experimentally studied the thermal characteristics of miniature loop heat pipe with sintered porous wick structure. The heat pipe is sintered with three different particle diameters i.e., 100 μm, 45 μm, 3 μm. The sintering formed with 3 μm diameter satisfies the different operating conditions of the heat pipe namely maximum capillary pressure, permeability, effective thermal conductivity and porosity.

It is concluded from the literature that all the researchers have proved the suspension of nanoparticles in base fluid will improve the performance of heat pipe. Many articles are experimentally analyzed the thermal performance of mesh and grooved wick structures, not much with sintered wick structure. In the present work, the thermal characteristics of copper sintered wick heat pipe are investigated using CuO and Al_2O_3 nanofluids. In addition, both the surface and vapor temperatures are experimentally measured to estimate the thermal performance of heat pipe.

2. Preparation and properties of nanofluids

Nanofluids preparation is the primary step of exploit nanofluids into the heat transfer applications. The CuO (97.5% pure) and Al_2O_3 (94.5% pure) nanoparticles are used in this study and the nanoparticles are the commercial product of Alfa Aesar, USA. In the present work, DI water based CuO and Al_2O_3 nanofluids are prepared using two step method. Initially, CuO and Al_2O_3 nanoparticles are separated based on their mass concentration viz. 0.5 wt.%, 1.0 wt.% and 1.5 wt.% separated. Later, the nanoparticles are dispersed in DI water. The solution is kept in ultrasonic homogenizer with 40 kHz frequency for the even distribution of nanoparticles during 60 min. No surfactants are added during the process as the addition of surfactant will deteriorate the thermal characteristics of nanofluids.

The size of nanoparticles has influences on the thermal properties of nanofluids. Especially, the normalized specific heat capacity

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