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Effect of nanofluid on thermal performance of heat pipe with two evaporators; application to satellite equipment cooling

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ABSTRACT

A study on the behavior of nanofluid in a cylindrical heat pipe with two heat sources is performed to analyze the nanofluid application in heat-dissipating satellite equipment cooling. Pure water, Al_2O_3–water and TiO_2–water nanofluids are used as working fluids. An analytical modeling is presented to predict the wall temperature profile for the heat pipe assuming saturated vapor and conduction heat transfer for porous media and wall, respectively. The effects of particle concentration levels ($\varphi=0$ (distilled water), 2, 4, and 8%), particle diameters ($d_p=10$, 20, and 40 nm) on the local wall temperature, heat transfer coefficient, thermal resistance, and the size of the heat pipe are investigated. It is observed that the better wall temperature uniformity can be achieved using nanofluid which results in lower temperature difference between evaporators and condenser sections. Results reveal that applying nanoparticle with smaller size and higher concentration level increases heat transfer coefficient remarkably by reducing thermal resistance of saturated porous media. It is also found that the presence of nanoparticles in water can lead to a reduction in weight of heat pipe, and thus satellite, under nearly identical condition. The findings of this paper prove the potential of nanofluid in satellite equipment cooling application.

1. Introduction

Thermal management is one of the most effective factors in the correct operation of various satellites. High temperature of heat-dissipating equipment such as frequency convertor, high power amplifier, and power supply can adversely affect satellite operation. Therefore, it is absolutely critical to remove the heat generated by these components. Heat pipe, as one of the most reliable and efficient heat exchanger, is often used to provide suitable thermal conditions for space applications, as addressed by some researchers [1–3]. However, a limiting factor for the thermal performance of a heat pipe is poor thermal conductivity of conventional fluids. To overcome this problem, the thermal conductivity of the working fluid should be improved [4].Many researchers have tried to improve the thermal properties of coolants by suspending extremely tiny particles into these fluids. This kind of fluid is called “nanofluid” which has firstly proposed by Choi and Eastman [5]. The application of nanofluid in various types of heat pipe has been carried out by several researchers which some of them are summarized by Alawi et al. [6], Sureshkumar et al. [7], and Liu and Li [8].

The first paper about using nanofluid in heat pipe was published by Chien et al. [9].The working fluid was a

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Nomenclature

C	constant in Eq. (15)
d	diameter [m]
E	constant in Eq. (14)
h	convective heat transfer coefficient [W/m^2 K]
I	modified Bessel function of first kind
k	thermal conductivity [W/m K]
K	modified Bessel function of second kind,
L	heat pipe length [m]
La	adiabatic length [m]
Le	evaporator length [m]
Lc	condenser length [m]
m	number of terms included in series calculation
n	natural number (1, 2, 3, …)
N	mesh number [1/m]
Q	heat load [W]
q''	heat flux[W/m^2]
R	radius [m], heat pipe thermal resistance[K/W]
r	cylindrical coordinates [m]
t	thickness of nanolayer [m]
T	temperature[m]
x	cylindrical coordinates [m]

Greek Symbols

β	ratio of nanolayer thickness to particle radius
ε	porosity of the wick
θ	relative temperature (T)
ρ	density [kg/m3]
λ	constant in Eq. (13)
φ	volume fraction of nanoparticle

Subscripts

a	adiabatic
bf	basefluid
eff	effective
l	liquid
nf	nanofluid
p	nanoparticle
o	outer surface of heat pipe
v	vapor, wich–vapor interface
w	wall, wall–wick interface

suspension with gold nanoparticles of an average diameter of 17 nm in water which was applied for a disk-shaped miniature heat pipe (DMHP). The results showed that a significant reduction in the thermal resistance of the DMHP can be found if nanofluid is used instead of DI-water. Shafahi et al. [4] proposed a two-dimensional modeling to investigate the thermal performance of a cylindrical heat pipe using Al_2O_3, CuO, and TiO_2 nanoparticles. They reported that the presence of nanoparticles within the liquid improves the thermal performance of the heat pipe by reducing the thermal resistance and an optimum mass concentration exists for nanoparticles in maximizing the heat transfer limitation. These authors [10] also utilized analytical models to evaluate the thermal performance of rectangular and disk-shaped heat pipes using nanofluids and reported similar results to their previous studies. Alizad et al. [11] studied thermal performance, transient behavior and operational start-up characteristics of flat-shaped heat pipe using nanofluid and showed an enhancement in the heat pipe performance for both flat-plate and disk shape heat pipes throughout the transient process. Tsai et al. [12] evaluated experimentally the application of gold–water nanofluid for cylindrical heat pipe and reported that adding nanoparticles into basefluid can decrease the thermal resistance of heat pipe between 20% and 37%.Kang et al. [13] studied the performance of a conventional 1 mm wick-thickness sintered circular heat pipe using water-based silver nanofluid as the working fluid. The experimental results demonstrated that the temperature difference between condenser and evaporator decreases 0.56–0.65 °C compared to DI-water at an input power of 30–50 W. Kumaresan et al. [14] conducted experiments for applying CuO nanoparticles dispersed in DI water to a copper sintered wick heat pipe. Experimental results showed a reduction in the thermal resistance of 66.1% and enhancement in the heat transfer coefficient and thermal conductivity of 29.4% and 63.5% is respectively, observed for 1.0 wt% of CuO–water nanofluid at 45° tilt angle compared with heat pipe kept at horizontal position. An experimental study was performed by Chen et al. [15] to investigate a new type of copper wire-bonded flat heat pipe using water, ethanol and nanofluids as working fluids. Experimental results show that using nanofluid can improve the heat transfer performance of the heat pipe and the best heat transfer performance of heat pipe is achieved at the concentration of 1.0 wt% under different saturation temperature conditions with different nanofluid. Hung et al. [16] carried out an experiment concerning a cylindrical heat pipe. The working fluid was an aqueous suspension of Alumina nanoparticle with three concentrations (0.5, 1.0, and 3.0 wt%). The heat pipe was a straight copper tube with an outer diameter of 9.52 mm and different lengths of 0.3 m, 0.45 m, and 0.6 m. It was found that at a heating power of 40 W, the optimal thermal performance for Al_2O_3/water nanofluid heat pipes measuring 0.3 m, 0.45 m, and 0.6 m was 22.7%, 56.3%, and 35.1%, respectively, better than that of pipes using distilled water as the working fluid. Putra et al. [17] studied the performance of a screen mesh wick heat pipe using Al_2O_3–water, Al_2O_3–ethylene glycol, TiO_2–water, TiO_2–ethylene glycol and ZnO–ethylene glycol nanofluids with different nanoparticle concentrations (1–5%). The screen mesh wick heat pipe with the best performance was that which used Al_2O_3–water nanofluid with 5% volume concentration. Using nanofluids in the heat pipes resulted in the formation of a thin coating on the screen mesh surface from the element of the nanoparticles which promotes good capillary structure.