International Communications in Heat and Mass Transfer 57 (2014) 208–215

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Comparative study on heat transfer characteristics of sintered and mesh wick heat pipes using CuO nanofluids☆

G. Kumaresan [a,*], S. Venkatachalapathy [a], Lazarus Godson Asirvatham [b], Somchai Wongwises [c]

[a] Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli 620015, Tamil Nadu, India
[b] Department of Mechanical Engineering, Karunya University, Coimbatore 641 114, Tamil Nadu, India
[c] Fluid Mechanics, Thermal Engineering and Multiphase Flow Research Lab (FUTURE), Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's University of Technology, Thonburi, 126 Bangmod, Tongkru, Bangkok 10140, Thailand

ARTICLE INFO

Available online 10 August 2014

Keywords:
Heat pipe
Nanofluid
Wick structure
Surface temperature
Thermal conductivity

ABSTRACT

An experimental investigation has been carried out to compare the enhancement in the thermal performance of sintered and mesh wick heat pipes by varying the working fluid, inclination angle and heat input. Similar geometrical specifications of 12, 330 and 1 mm respectively are selected for the outer diameter, length and wick thickness and kept constant for both sintered and mesh wick heat pipes. The study focuses on changes in surface temperature distribution, thermal resistance and effective thermal conductivity of heat pipes. The results showed that the maximum reduction in surface temperature is obtained for sintered wick heat pipe at 45° tilt angle and 60° for mesh wick heat pipe with CuO/DI water nanofluid concentration at 1.0 wt.% for both the cases. The reduction in thermal resistance of sintered wick heat pipe is 13.92% higher compared with mesh wick heat pipe for the same heat input, mass concentration and inclination angle. Presence of CuO nanoparticles in DI water and increasing heat input tremendously increases the thermal conductivity of heat pipes. An important observation from this study is the sole effect of sintered wick in heat pipe not only reduces the thermal resistance but also increases the heat transport capacity up to 20 W compared with that of mesh wick.

1. Introduction

Phase change heat transfer is suitable for transferring large amount of heat compared with single-phase convective heat transfer. This is because the heat transfer coefficient associated with the boiling and condensation processes are high. Heat pipe is one of such a passive device, which works on the principle of phase change heat transfer. The contribution of heat pipe to the engineering field is remarkable and some of the applications are electronics cooling [1,2], solar heaters [3], air conditioning [4] and HVAC system [5]. Particularly, electronic field is the fast developing one and the heat dissipation in electronic devices is the major problem up-to-date. The performance of heat pipe is limited to the thermal properties of working fluid. Recently, the nanofluids are used to improve the performance of heat pipes instead of conventional fluid. Various authors reported the use of nanofluids instead of base fluids led to a massive reduction in heat pipe thermal resistance [6–8] and wall temperature [6,8,10], meanwhile increase in the thermal conductivity [9,11,12] of heat pipe. Hussein et al. [13] conducted an elaborative review on the heat transfer enhancement and hydrodynamic characteristics of nanofluids. They concluded that the thermal properties of solid nanoparticles enhance the hydrodynamic and heat transfer characteristics of the base fluid. Bahiraei [14] presented an overview on different numerical approaches for simulation in nanofluids. The authors suggested that the use of two phase approach would give better understanding of nanofluids than single phase approach. Loh et al. [15] conducted a study on heat pipes with different wick structures viz. mesh, grooved and sintered metal powder. The test was conducted with increasing power input and the heat pipe orientation was varied from −90° to +90°. They concluded that the sintered powder metal wick structure performance was better compared with mesh and grooved wicks. This is due to the good capillary action in sintered wicks. Putra et al. [16] tested the thermal performance of screen mesh wick heat pipe using Al_2O_3, TiO_2 and ZnO nanoparticles in DI water and ethylene glycol base fluids. They observed a decreasing trend in the temperature difference of the heat pipes with increasing concentrations of Al_2O_3 nanofluids.

Tsai et al. [17] investigated the thermal performance of circular mesh wick heat pipe with Au/DI water nanofluid. The authors reported a reduction in thermal resistance with gold nanofluid compared with DI water. Kempers et al. [18] conducted an experimental study in mesh wick heat pipes by varying the number of wick layers, 1, 2, 3 and 6. They found that the performance of heat pipe was maximum with three layers of mesh wick and observed the lowest thermal resistance. Kumaresan et al. [19] experimentally investigated the thermal

☆ Communicated by W.J. Minkowycz.

* Corresponding author.
E-mail addresses: kumareshgct@gmail.com, 411111053@nitt.edu (G. Kumaresan).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.08.001
0735-1933/

Nomenclature

A	surface area (m^2)
D	outer diameter (mm)
d	particle size (nm)
I	current (A)
k	thermal conductivity (W/m°C)
L	length (mm)
Q	heat supplied (W)
R	thermal resistance (°C/W)
T	temperature (°C)
V	voltage (V)
ΔT	temperature difference (°C)

Subscripts

c	condenser
c/s	cross-sectional
e	evaporator
hp	heat pipe
s	surface

Greek symbols

θ	inclination angle (°)
μ	dynamic viscosity (cP)
ω	weight fraction (wt.%)
Δ	increment

characteristics of copper sintered wick heat pipe with CuO/DI water nanofluids. The authors compared the surface and vapor temperatures of heat pipe and they observed a difference of 5.1 °C at the evaporator section. Kang et al. [20] experimentally investigated the thermal performance of sintered wick heat pipes with 10 and 35 nm size silver nanoparticles. It was found that the addition of nanoparticles considerably reduced the temperature difference between the evaporator and condenser ends and enhanced the heat transfer capacity of heat pipe up to 28.6% compared with DI water. Liu and Zhu [21] studied the performance of horizontal mesh wick heat pipe with different concentrations of CuO/DI water nanofluids at subatmospheric pressures. An optimum concentration of CuO nanoparticles and lower operating pressure were found to increase the heat transfer rate of heat pipe. Kumaresan et al. [22] indicated in their review, that the use of nanoparticles in the conventional fluid diminished the heat pipe dry out problems and increased its heat transport capacity. They also reported that the heat pipe orientation plays an effective role on its performance.

Based on the literature review, it is concluded that the suspension of nanoparticles in base fluid improves the thermal performance of heat pipes. There are many references available in heat pipes with mesh and sintered wicks, but none of them compared the thermal performance using these two wicks at fixed geometric and operating conditions. The effect of tilt angle on the performance of heat pipe using nanofluid is not much reported. This study effectively compares the performance of heat pipes viz. surface temperature distribution, thermal resistance and thermal conductivity using sintered and mesh wick structure, varying the working fluid, inclination angle and heat input.

2. Nanofluid preparation and its thermophysical properties

The surfactant free CuO/DI water nanofluid is prepared using a two-step method. Commercial CuO nanoparticles supplied by Alfa Aesar, USA is used in this study. The particles are spherical in shape and the maximum size is within 50 nm. The prepared solution is kept in an ultrasonicator for a duration of 1 h with 45 kHz frequency for better stability. Fig. 1(a) depicts the particle size distributions of CuO nanoparticles dispersed in DI water. The size of CuO nanoparticles has already been measured by the present authors and reported [19] using X-ray diffraction analysis. The Scherrer's formula is used to find the particle size and the result showed that the size of the particles does not exceed 39.1 nm. Further, a stability test has also been conducted for the mass concentration of 1.0% by keeping the prepared nanofluid statically for 60 days. After 60 days, a dynamic light scattering analysis (Zetasizer Nano ZS-Malvern) was conducted and from the results, the size of the nanoparticles was found to be around 250 nm. The increased size of the nanoparticles may be due to the slight agglomeration during the stability period. The prepared sample is kept for 60 days and no separation line was found between the nanoparticles and water. However, to ensure the stability of nanofluid, a Zeta potential test is conducted by Zetasizer and is shown in Fig. 1(b). The value for the given sample is +31.4 mV (a value above ±30 mV is believed to have good electrostatic stability), which confirms that the quality of the prepared sample is good and stable.

The thermophysical properties of the working fluid can be improved by the dispersion of CuO nanoparticles in the base fluid, mainly due to the enhancement in the thermal conductivity. Also, the addition of CuO nanoparticles increases the viscosity of working fluid and higher viscosity creates more restriction to the fluid flow. Hence, the thermal conductivity and viscosity of working fluid are experimentally measured. The thermal conductivity of CuO/DI water with different mass concentrations, viz. 0.5, 1.0 and 1.5 wt.% are measured by a KD2 Pro thermal properties analyzer (Decagon Devices, Inc., USA). The increases in the value of thermal conductivity for 0.5, 1.0 and 1.5 wt.% of CuO nanofluids are 0.96, 2.37 and 5.08% respectively. A Brookfield viscometer is used to measure the dynamic viscosity of nanofluid and it increases with mass concentration of CuO nanoparticles. The increases in viscosity for 0.5, 1.0 and 1.5 wt.% of CuO nanofluids are 8.91, 11.67 and 16.46% respectively. Rise in temperature of the working medium gradually reduces the viscosity and a maximum reduction of 54.93% is found for 1.5 wt.% of CuO/DI water nanofluid at 80 °C compared with 33 °C.

3. Heat pipe test rig and experimentation

The heat pipe used in this study has a length of 330 mm, an outer diameter of 12 mm and a thickness of 1 mm with copper as the pipe

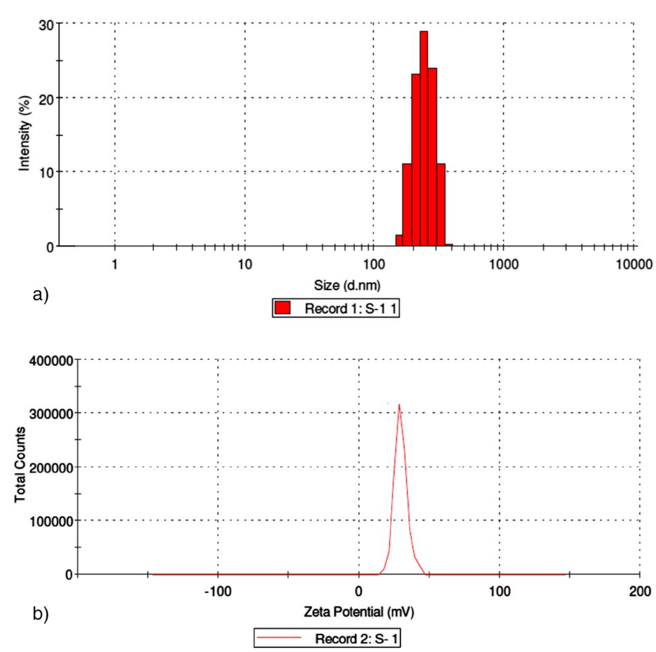

Fig. 1. (a) Particle size distribution and (b) Zeta potential analysis of CuO/DI water nanofluid.