International Communications in Heat and Mass Transfer 67 (2015) 14–20

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Thermal performance of inclined screen mesh heat pipes using silver nanofluids☆

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ARTICLE INFO

Available online 2 July 2015

Keywords:
Heat pipe
Nanofluid
Thermal resistance
Inclination
Screen mesh

ABSTRACT

This study presents the effect of silver nanofluid on thermal performance of inclined screen mesh heat pipe in cooling applications. Four cylindrical copper heat pipes containing two layers of screen mesh were fabricated and tested with distilled water and water based silver nanofluids with mass concentrations of 0.25%, 0.5% and 0.75% as working fluids. The experiments were performed at four inclination angles of 0°, 30°, 6° and 90°. The main focus of this study is to investigate inclined heat pipe performance with nanofluid. Experimental results indicate that the thermal performance of heat pipes was improved with nanofluids compared to water and thermal resistance of the heat pipes decreased with the increase of nanoparticle concentration. Moreover, the thermal performance of the heat pipes at inclination angle of 60° is found to be higher than other tested inclination angles, which shows the effect of gravity on heat pipe performance.

1. Introduction

Heat pipe as a two phase heat transfer device, with high effective thermal conductivity in comparison with common thermal conductors such as metal rods and fins, plays a vital role in many industrial applications including cooling of electronics, power generation, aerospace and chemical processes. Large quantities of heat with minimum temperature gradient are transported by vaporization and condensation of a working fluid and also capillary force action for pumping the liquid back to the evaporation section. However, traditional heat transfer fluids like water and alcohols have been extensively used in heat pipes, their poor thermal properties become a primary obstacle limiting the thermal performance of heat pipe-heat exchangers. Nanofluids, as a new class of heat transfer fluids, are proposed and developed over the past decade for heat transfer applications. It has been revealed that nanofluids have greater heat transfer characteristics than traditional heat transfer fluids [1–8]. A novel idea which has been suggested is to utilize nanofluid as a working fluid in heat pipes to enhance heat pipes thermal efficiency. During recent years, researchers have concentrated mainly on investigation of nanofluids on heat pipe performance at different working conditions [9–16]. Different types of nanofluids such as water based copper, aluminum oxide and silver nanofluids have been used in the common types of heat pipes primarily include cylindrical heat pipes [17,18], oscillating heat pipes [19,20] thermosyphons [21] and pulsating heat pipes [22] and it has been shown that nanofluids can effectively improve the heat transfer performance of heat pipes. Kang et al. [23] studied the effect of silver nanofluids on thermal performance of a sintered heat pipe experimentally. They investigated the effects of nanoparticles size and concentration on thermal performance of the heat pipe. They found that the wall temperature difference of the heat pipe using nanofluid decreased 0.56–0.65 °C at an input power of 30–50 W. Wang et al. [24] performed experiments to investigate the effect of CuO nanofluids on a cylindrical miniature grooved heat pipe. They found that heat transfer coefficient and maximum heat flux were increased significantly for the heat pipe with nanofluid. Asirvatham et al. [25] carried out an experiment to study the heat transfer performance of a screen mesh heat pipe using silver nanofluids with average nanoparticle diameter of 58 nm. They found that using nanofluid enhanced the heat pipe thermal efficiency. The thermal resistance decreased by 76% for silver nanofluid with volume concentration of 0.009%. Do et al. [26] studied the thermal performance of screen mesh heat pipe using water based Al_2O_3 nanofluids. Based on their experiments, the thermal resistance at the evaporator-adiabatic section decreased by 40% at volume concentration of 3% compared with water. Furthermore, the maximum heat flux with nanofluid was found to be higher than that with water. Effect of inclination angle on the thermal performance of heat pipe with nanofluid has been investigated in some experimental studies as summarized in Table 1.

It can be seen that the inclination angle affects the thermal performance of the heat pipes remarkably. In this study, effect of inclination angle on thermal performance of the heat pipes with silver/water nanofluids at three different mass concentrations of 0.25%, 0.5% and

☆ Communicated by W.J. Minkowycz.

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http://dx.doi.org/10.1016/j.icheatmasstransfer.2015.06.009
0735-1933/

Nomenclature

A	area, m
h	heat transfer coefficient, W/m^{2}K
k	thermal conductivity, W/mK
L	length, m
Q	heat input, W
R	thermal resistance, K/W
T	temperature, K

Subscripts

a	adiabatic
c	condenser
deg	degree
e	evaporator
eff	effective
vap	vapor

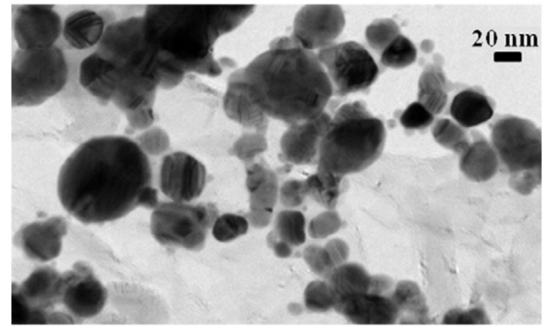

Fig. 1. TEM images of silver nanoparticles.

0.75% is studied experimentally and the results are compared with those of the heat pipe with water. The aim of this study is to evaluate the feasibility of using water based silver nanofluids in inclined heat pipes and assesses its thermal performance.

2. Experimental apparatus and procedure

2.1. Working fluid

Commercial stable Ag nanofluid (NF) with 0.75 wt.% was purchased and nanofluids with 0.5 wt.%, and 0.25 wt.% were prepared by diluting the original suspension. All nanofluids were stable for six months without any visual precipitation. Transmission electron microscopy (TEM) analysis of the Ag nanoparticles (NPs) size and morphology was performed using JEOL 2100 at 200 kV acceleration. Average hydrodynamic particle size distribution of Ag nanoparticles was assessed by Beckmann–Coulter Delsa Nano C system. The thermal conductivity of nanofluids was measured by using TPS 2500 instrument, which works based on transient plane source (TPS) method. The viscosity of Ag nanofluids was evaluated using DV-II + Pro-Brookfield viscometer.

Morphology of Ag nanoparticles was analyzed by TEM and the micrograph is displayed in Fig. 1. As one can see from TEM micrograph Ag nanoparticles have spherical morphology, with estimated average size of 30 nm. It is also important to analyze the size of Ag nanoparticles in the base working fluid media. For this purpose, dynamic light scattering (DLS) analysis was carried out and the result is shown in Fig. 2. Based on DLS the hydrodynamic size for Ag nanoparticles in water media was estimated in the range of 15–650 nm with an average hydrodynamic size of 165 nm. The difference between primary size obtained from TEM and solvodynamic size estimated by DLS may be due to use of surface modifiers in the commercial suspensions. These additives are used to stabilize the Ag nanoparticles in water base working fluid. Thermal conductivity and viscosity of water based silver nanofluids are listed in Table 2. Moreover, the experimental results are compared with Maxwell and Einstein correlations for thermal conductivity and viscosity, respectively. For better understanding of nanoparticle concentration effect on thermal conductivity and viscosity, a wider range of concentration (0–2 wt.%), compared to the range employed in this study (0–0.75 wt.%), is used for nanofluid property evaluation. The results exhibit that the thermal conductivity and viscosity of the nanofluid are dependent on the concentrations of nanoparticles. It is observed that the thermal conductivity of the nanofluid increased by 6.6%, 8% and 9% for the nanoparticle concentrations of 0.5 wt.%, 1 wt.% and 2 wt.%, respectively. Comparing the thermal conductivity results with those of predicted with Maxwell equation, it is found that the model underestimates the thermal conductivity of Ag nanofluid where the differences between the predicted and measured results are 6%, 7% and 8% for the nanoparticle concentrations of 0.5 wt.%, 1 wt.% and 2 wt.%, respectively. According to the results, viscosity of the silver nanofluids increases about 3% for all three concentrations compared to that of the base fluid. Comparing the results with the predicted ones with Einstein Model, about 2% difference between experimental and predicted results is observed, which means that Einstein model is able to predict the viscosity of the Ag nanofluid at very low concentration with good accuracy.

2.2. Experimental apparatus

The experimental test facilities consist of a cooling system with constant temperature bath, a pump (Gear pump, MCP-Z, Ismatec, Switzerland) and flow meter (Coriolis flow meter, CMFS015, Micromotion, Netherlands), a power supply (DC power supplier, PSI 9080-100, Elektro-Automatik GmbH, Germany), a data acquisition system (Agilent 34970A, Malaysia) and the main test section as shown in Fig. 3. The heat pipe is made of a copper tube with length of 20 cm, diameter of 6.35 mm and wall thickness of 0.71 mm. Each heat pipe has 2 layers of 150 mesh (150 strands per inch or 25 mm). Aperture size and wire diameter of screen mesh are 0.106 mm and 0.063 mm, respectively. For the optimum performance and reliability in terms of charge amount and pressure inside the pipes, all heat pipes were built, evacuated and filled at Thermacore Co. which is one of the heat pipe manufacturers in Europe. The evaporator, adiabatic and condenser sections of the heat pipe were 50 mm, 100 mm and 50 mm long, respectively. At the evaporator section, an electrical cartridge heater provides uniform heat flux to the copper heating blocks attached to the heat pipe. The condenser section was cooled by circulating water in a constant-temperature cooling bath at the temperature and flow rate of 288 K and 51 kg/h, respectively for keeping steady cooling conditions in the condenser section. The

Table 1
Inclination angle effect on heat pipe with nanofluid studied in literature.

Author	Nanofluid	Size and concentration	Observations
Wang et al. [27]	Water/CuO	50 nm & 0.5–2.0 wt.%	The inclination angle of 45° corresponds to the best thermal performance for heat pipes
Hung et al. [15]	Water/Al_2O_3	20 nm & 0.5–3.0 wt.%	The tilt angle that maximizes the thermal performance of the heat pipe ranges from 40° to 70°
Teng et al. [28]	Water/Al_2O_3	20–30 nm & 0.5–3.0 wt.%	The optimal thermal efficiency for heat pipes occurred at 60°
Liu et al. [29]	Water/CuO	50 nm & 0.5–2.0 wt.%	The inclination angle of 45° corresponds to the best thermal performance for heat pipes
Senthilkumar et al. [30]	Water/Cu	40 nm & 100 mg/lit	Best thermal performance is reported at 45°