International Communications in Heat and Mass Transfer 76 (2016) 294–300

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Comparative study of the effect of hybrid nanoparticle on the thermal performance of cylindrical screen mesh heat pipe☆

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ARTICLE INFO

Available online 27 May 2016

Keywords:
Screen mesh heat pipe
Hybrid nanofluid
Thermal resistance
Heat load

ABSTRACT

The thermal performance of a cylindrical screen mesh heat pipe with hybrid nanofluid was experimentally investigated. The hybrid nanofluid was prepared by mixing Al2O3 and CuO nanoparticles with deionised water. The heat pipe was fabricated with straight copper tube of dimensions 300 mm length, 12.5 mm outer diameter and 1 mm thickness. The wick structure in the heat pipe was created by a three layer copper screen mesh of 100 mesh size. The heat input to the heat pipe was varied from 50 W to 250 W in five equal steps. The heat pipe was tested with three hybrid nanofluids made with combinations of Al2O3 and CuO nanoparticle in DI water (Al2O3 75%–CuO 25%, Al2O3 50%–CuO 50% and Al2O3 25%–CuO 75%). The tested hybrid nanofluids were made with 0.1% volume concentration of Al2O3 and CuO nanoparticle combination in deionised water. The results of the investigation showed that for the maximum heat load of 250 W considered in this work, the thermal resistance of the hybrid nanofluid with combination, Al2O3 25%–CuO 75%, showed 44.25% reduction compared to deionised water. The reduction in thermal resistance is due to the formation of porous coating on the wick surface which increases the wettability and surface roughness thereby creating more nucleation sites as seen in the SEM images. From the experimental investigation, it was observed that hybrid nanofluids are alternative to the conventional working fluids in heat pipes for electronic cooling applications.

1. Introduction

The heat flux generated in highly integrated electronic devices and systems is multiplied due to the downsizing of the devices. This higher heat fluxes lead to reduced performance level and lifespan of these devices and systems. Conventional cooling techniques like fans, heat sinks etc. in ultra slim devices, are inadequate to meet this challenge and therefore other alternative efficient thermal management techniques are required [1,2]. Among these passive cooling methods, heat pipes have garnered more attention and established a major role in the thermal management domain due to their high thermal conductivity and reliability. These devices will not consume mechanical energy and its thermal performance depends upon the wick structure, working fluid and the heat flux applied. The phase change phenomena of the working fluid play a major impact on the thermal performance of the heat pipes. The role of different working fluids on the thermal performance has been investigated by many researchers [3–8]. However, recently nanofluids containing wide variety of nanoparticles in base fluid as working fluid in heat pipes have become a subject of interest for many of the researchers [9–22]. In all the above studies it was reported that nanofluid as working fluid can improve the thermal performance of heat pipes.

It is worth to mention here that the role of hybrid nanofluid as a potential working fluid for heat pipes has also been investigated by a few researchers. Han and Rhi [23] conducted an experimental investigation to study the thermal characteristics of grooved heat pipe with different volume concentrations of nanofluid namely, Ag–H2O, Al2O3–H2O and Ag/Al2O3–H2O hybrid nanofluid. The volume concentration of working fluid, inclination, temperature of the cooling water and heat input was varied and studied. It was proved that the present hybrid working system, pure nanoparticle fluid system was better than hybrid nanofluids system. A mixture of Al2O3 and CuO nanoparticles in water having 0.1 vol% concentration were utilised by Suresh et al. [24] to experimentally investigate the Nusselt number and friction factor of laminar flow through a tube of circular cross section. A 10.94% increase in Nusselt

☆ Communicated by W.J. Minkowycz.
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http://dx.doi.org/10.1016/j.icheatmasstransfer.2016.05.030
0735-1933/

Nomenclature

A_c	Area of cross section of the heat pipe, mm^2
d	Diameter of the heat pipe, mm
I	Current, A
k_{eff}	Effective thermal conductivity, W/mK
K	Shape factor
L	Length of the heat pipe, mm
Q	Heat load ($V \times I$), W
R_{HP}	Thermal resistance of heat pipe, (°C/W)
$\overline{T}_E$	Average evaporator surface temperature, °C
$\overline{T}_C$	Average condenser surface temperature, °C
V	Voltage, V
SEM	Scanning electron microscope
TEM	Transmission electron microscope
XRD	X-ray diffraction

Greek symbols

λ	Wave length of X-ray, A^0
θ	Braggs angle, deg
β	Value of full width at half maximum, rad

number compared to pure water was obtained as the result of this investigation. Furthermore, a maximum enhancement of 13.56% in Nusselt number at a Reynolds number of 1730 was also obtained by using hybrid nanofluid.

However the study on thermal performance of heat pipes using hybrid nanofluids for improving its heat transfer characteristics is still in the initial stage. More and more research needs to be carried out because the different combinations and volume concentration of different nanoparticles can influence the performance characteristics of many heat transfer equipments, especially in the heat pipes. In the present study, experiments have been conducted to evaluate the feasibility of using three different combinations of nanoparticles of Al2O3 and CuO forming hybrid nanofluids in cylindrical mesh wicked heat pipes and compared their thermal performance with deionised (DI) water.

2. Experimentation

2.1. Preparation of nanofluid

Two different nanoparticles (Al2O3 and CuO) were used in the present experimental work. Al2O3 nanoparticles were manufactured by Alfa Aesar USA (product number 44931 of below 50 nm) and CuO nanoparticles were manufactured by Skyspring Nanomaterials Inc., Houston, USA (product number 2810-071814). The first key step in the experimental work is the preparation of nanofluid. In the present investigation, the hybrid nanofluid was prepared by mixing Al2O3 and CuO nanoparticles of volume concentration 0.1% mixed with deionised water as the base fluid. In order to get a uniform and stable nanofluid, it is then sonicated for 1 h in an ultrasonic cell disruptor (model KS500F). Three different combinations of hybrid nanofluid such as Al2O3 75%–CuO 25%(hybrid nanofluid-1), Al2O3 50%–CuO 50% (hybrid nanofluid-2) and Al2O3 25%–CuO 75% (hybrid nanofluid-3) having a total 0.1% volume concentration were used for the study.

2.2. Characterisation of Al2O3 and CuO nanoparticles

The crystalline phase and structural characterisation of Al2O3 and CuO nanoparticles were determined by X-ray diffraction (using Shimadzu LabX-6000) method. The XRD image depicted in Fig. 1 shows that the peak pattern in the diffractograms are broad, and this

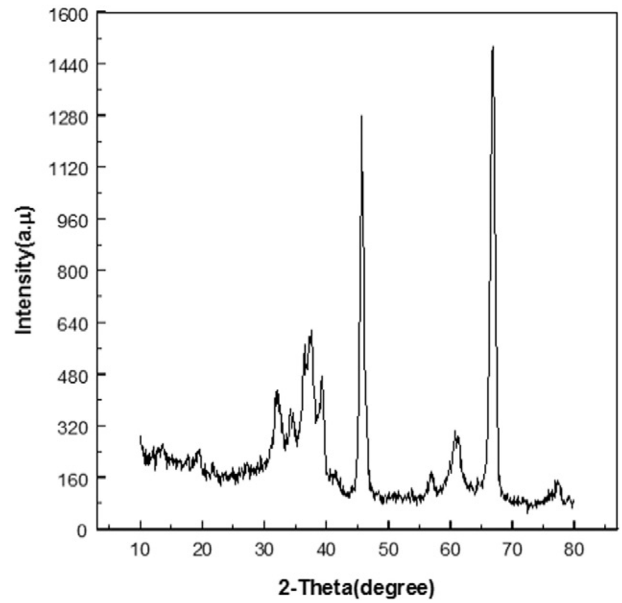

Fig. 1. XRD pattern of Al2O3 nanoparticle [26].

confirms the crystalline nature of the Al2O3 nanoparticle. The average crystalline size of Al2O3 nanoparticle was calculated using the Scherrer [25] formula given below.

$$D = \frac{K\lambda}{\beta \mathrm{Cos} 2\theta} \quad (1)$$

In the above equation 2θ corresponding to the maximum intensity was found to be 66.82 (Fig. 1). The β obtained by the XRD data process sheet was found to be 0.8821. Based on this the average size of Al2O3 was found to be 14.38 nm. To further confirm that the nanoparticles of Al2O3 used for this study was below 50 nm the transmission electron microscope image (using JEOL TEM 2100 model) was taken (Fig. 2). From this figure it can be seen that the average size of Al2O3 is below 50 nm. Similar XRD images were taken for CuO nanoparticles and the average particle size was found to be 17.36 nm. The TEM images of CuO were taken inhouse and the average size for CuO nanoparticle was found to be below 50 nm. The XRD image and TEM for CuO are not shown here for brevity.

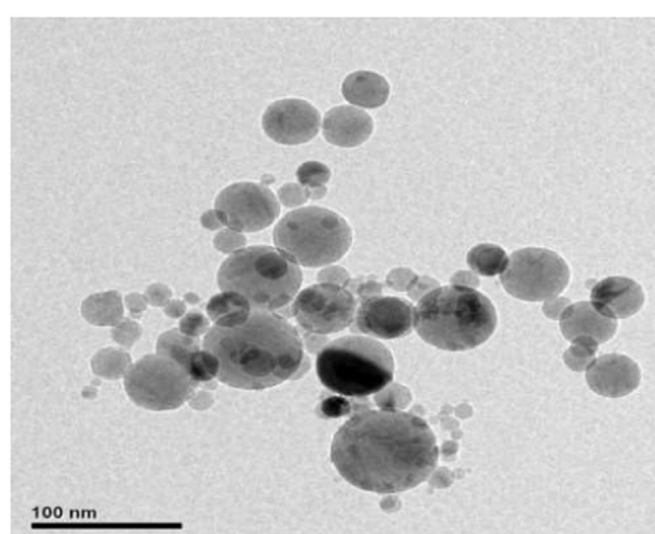

Fig. 2. TEM image of Al2O3 nanoparticle.