INTERNATIONAL JOURNAL OF REFRIGERATION 43 (2014) 62–70

Available online at www.sciencedirect.com

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Experimental study on thermal performances of heat pipes for air-conditioning systems influenced by magnetic nanofluids, external fields, and micro wicks

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ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form
8 April 2014
Accepted 9 April 2014
Available online 18 April 2014

Keywords:
Heat pipes
Thermal performance
Magnetic nanofluids
Micro wicks

ABSTRACT

Previous studies have typically indicated that only one composition factor, such as wick structures or working fluids, affects the thermal resistance or critical heat flux of heat pipes. In this study, the composition factors influencing thermal performance, such as wick structures, working fluids, the modulation fields of working fluids, and combinations of these factors, were thoroughly investigated. The evaluated materials comprised microgrooved, sintered, and wickless heat pipes; magnetic nanofluids exhibiting volumetric fractions (vol.) of 0.16%–3.20%; and deionized water. A strong magnetic field of 200 Oe was applied. The results indicated that combining grooved heat pipes and a 0.80% vol. of magnetic nanofluids or sintered heat pipes and a 0.16% vol. of magnetic nanofluids yielded the optimal promotions: the thermal resistance was reduced by approximately 80% and the critical heat flux was enhanced 2.7-fold compared with general wickless heat pipes filled with deionized water. These findings should serve as a valuable reference when designing heat pipe exchangers for use in air-conditioning systems.

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Etude expérimentale sur les performances thermiques de caloducs pour des systèmes de conditionnement d'air, influencée par les nanofluides magnétiques, les champs externes, et les micro-mèches.

Mots clés : Caloducs ; Performance thermique ; Nanofluides magnétiques ; Micro-mèches

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http://dx.doi.org/10.1016/j.ijrefrig.2014.04.007
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Nomenclature

R	thermal resistance (°CW^{-1})
CHF	critical heat flux (W)
HP	heat pipe
WF	working fluid
MNFs	magnetic nanofluids
vol	volumetric fractions (%)
DI	deionized
AC	air conditioning
NFs	nanofluids
HTR	heat transfer rate (W)
Q	input power (W)
T	temperature
Subscripts	
in	inlet of test section
C	condenser
e	evaporator

1. Introduction

With the fast temperature increase of global warming as well as the energy crisis, it is urgent to promote the efficiency of air conditioning (AC). Hence, in addition to an active heat pump, the improvement of thermal performance of heat pipes (HPs), making up a passive AC exchanger (as shown in Fig. 1) (ASHRAE, 2000), is an important subject. Although an HP is also called a heat superconductor, its mechanism, unlike that of low electric resistance superconductors, uses latent heat absorption and release through the rapid transportation of working fluids between the evaporation and condenser sections of the HP tube. Therefore, efforts to improve thermal performance focus on pipe materials, wick structures, and working fluids (WFs).

The selection of the pipe material, which depends on the operating temperature range and application requirements, may be copper, nickel, aluminum, and stainless steel. However, copper is usually used in commercial products because of its high conductivity and ease of manufacturing. Researchers have proposed many wick structures of grooves, mesh, channels, and sintered powders to return liquid WFs from the condenser section to the evaporation section (Dunn and Ready, 1994). However, most wicks have limited capillary performance, and are sensitive to the HP orientations. Sintered wicks generally have better capillary performance and critical heat flux (CHF) values in addition to orientation independence (Peterson, 1992; Sobhan et al., 2007; Cao et al., 2002).

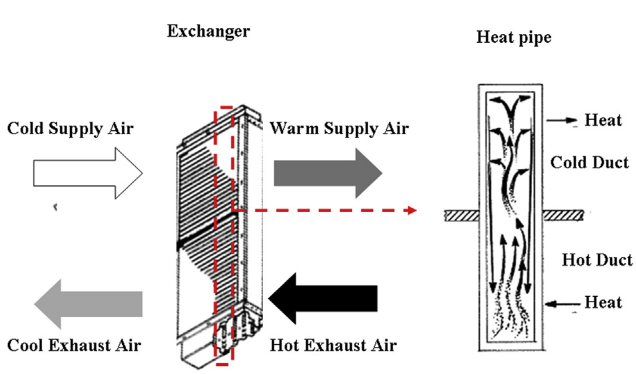

Fig. 1 – An HP application in air-conditioning systems.

Nanofluids (NFs) have recently become attractive solutions for wickless HPs because of their superior thermal conductivity (Cieslinski and Kaczmarczyk, 2011; Yang and Liu, 2011; Chiang et al., 2012). Magnetic nanofluids (MNFs) in particular have the unique characteristics of tunable thermal conductivity under a magnetic field (Chiang et al., 2012). In addition to the reduction of thermal resistance (R), the combination of wickless HPs and NFs induces a contradicting phenomenon. The over-deposited nanoparticles deteriorate pool boiling heat transfer on smooth tubes. Hence, a higher NF concentration leads to a lower heat transfer rate (HTR) (Cieslinski and Kaczmarczyk, 2011; Yang and Liu, 2011). However, this deposition can be effectively avoided with a special design of a nozzle for the flow pattern of the slug and vapor (Chiang et al., 2012) or an oscillating heat pipe (Ma et al., 2006). The second phenomenon is a CHF enhancement in pool boiling because of the deposited nanoparticles (Cieslinski and Kaczmarczyk, 2011; Yang and Liu, 2011; You et al., 2003). Nanofluids demonstrate higher-quality contributions on a rough surface than on a smooth surface (Das et al., 2003). Therefore, some researchers have studied the thermal performance of wick HPs by using NFs as WFs (Do et al., 2010; Yang et al., 2008; Do et al., 2010; Kang et al., 2009). Summarily, Table 1 shows the HP compositions and their relations to the key performances of R and CHF. However, the different combinations of NFs and wick-structure HPs without conducting complete studies make it difficult to investigate the impacts of only NFs, NF modulation similar to external fields, wick structures, and the combination of thermal characteristics of the HPs.

Hence, this study presents complete experiments involving various combinations of three HP structures (wickless and two wick types), MNFs of four concentrations, and a magnetic field of MNF modulation. The thermal mechanisms induced by these HP factors are discussed.

2. Experimental materials and methods

2.1. Characteristics of magnetic nanofluids

The MNFs used in this study (Taiwan Advanced Nanotech Corp., Taiwan) were composed of water solvent and magnetic nanoparticles. The hydrodynamic diameter of magnetic nanoparticles by dynamic laser scattering was mainly in the range of 8–30 nm (Fig. 2(a)) (Nanotrac 150, Microtrac Corp., USA). A scanning electron microscope (SEM) by Tabletop Microscope (TM-1000, Hitachi Corp., Japan) showed similar results (Fig. 2(b)). The crystals were measured using an X-ray diffractometer (D-500, Siemens Corp., Germany) to determine the material composition, and the results are in agreement with the standard diffraction spectrum of Fe_3O_4 (JCPDS no. 65-3107)(Chiang et al., 2012). These results confirm that the particle material was Fe_3O_4. The magnetization-field (M–H)

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