INTERNATIONAL JOURNAL OF REFRIGERATION 82 (2017) 189–198

Available online at www.sciencedirect.com

ScienceDirect

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

Experimental investigation on the influence of high temperature on viscosity, thermal conductivity and absorbance of ammonia–water nanofluids

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ARTICLE INFO

Article history:
Received 29 November 2016
Received in revised form 26 April 2017
Accepted 30 May 2017
Available online 2 June 2017

Keywords:
Ammonia–water nanofluid
Viscosity
Thermal conductivity
Hysteresis phenomenon
Heating

ABSTRACT

To select the optimal ammonia–water nanofluids and apply to ammonia–water absorption refrigeration systems (AARS), this paper investigated the influence of heating on viscosity, thermal conductivity and absorbance of binary nanofluids. The hysteresis phenomenon was observed after heating at high temperature which is rarely reported in the literature. Experimental results show that most of nanofluids' thermal conductivity increased by about 3–12% after heating. However, their viscosities increased by as much as 15% to 25% except the γ-TiO_2 ammonia–water nanofluid, which was reduced by 2% to 7%. This study also shows that the trend of viscosity is consistent with the absorbance. Due to fact that the thermal conductivity of γ-TiO_2/NH_3–H_2O mixture increased after heating, while the viscosity decreased, even if the concentration of the base liquid is 12.5% or 25%, therefore it is the optimal choice for practical research in AARS at present.

Étude expérimentale sur l'influence de la température élevée sur la viscosité, la conductivité thermique et l'absorbance des nanofluides ammoniac-eau

Mots clés : Nanofluide ammoniac-eau ; Viscosité ; Conductivité thermique ; Phénomène d'hystérésis ; Chauffage

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http://dx.doi.org/10.1016/j.ijrefrig.2017.05.030
0140-7007/

Nomenclature

$A_{0,1,2}$	calculation constants in Eq. (2)
A	absorbance
b	optical path [cm]
c	molar concentration [mol l^{-1} 1^{-1}]
I_i	incident light intensity
I	transmitted light intensity
k_a	thermal conductivities of ammonia [W m^{-1} K^{-1}]
k_w	thermal conductivities of water [W m^{-1} K^{-1}]
k_L	thermal conductivities of ammonia or water [W m^{-1} K^{-1}]
k_{nf}	thermal conductivity of nanofluid [W m^{-1} K^{-1}]
k_f	thermal conductivity of ammonia–water [W m^{-1} K^{-1}]
μ_f	viscosity of ammonia–water [mPa·s]
μ_{bf}	viscosity of base fluid [mPa·s]
μ_{nf}	viscosity of nanofluid [mPa·s]
i_k	effective thermal conductivity ratio
i_μ	effective viscosity ratio
R	gas constant [8.314 J mol^{-1} K^{-1}]
T	temperature [K]
x	mole fraction of ammonia–water
ε	molar absorptivity [l mol^{-1} cm^{-1}]
φ	volume fraction of nano-particles
φ_m	maximum particle fraction determined by experiment
ψ	ratio of inter-particle spacing and particle radius

Subscripts

a	ammonia
w	water
f	ammonia–water
bf	base fluid
nf	nanofluid without heating
nf-heated	heated nanofluid

1. Introduction

Karl et al. (2015) presented an updated global surface temperature analysis which revealed that global trends were higher than those reported by the Intergovernmental Panel on Climate Change, especially in recent decades. The central estimate for the rate of warming during the first 15 years of the 21st century is at least as great as the last half of the 20th century. At the same time, the global energy consumption is increasing year by year, but global energy storage is limited.

However, refrigeration and air conditioning has become an indispensable part of life and industry, and one of the main areas of energy consumer and greenhouse gas maker at the same time. In this severe situation, ammonia absorption refrigeration (AARS) has become a research hotspot again. The reason being it has own superiority by utilizing low-grade heat sources without the threats of ozone depletion and global warming and outputting the considerable cooling capacity. Thus, it is not surprising that more and more attention has been drawn to it within research communities in recent years. But the reasons why it was neglected by researchers before this period are its low refrigeration performance and bulky size equipment in practical engineering system. Therefore, the researchers in this field focus on enhancing the efficiency of AARS in particular, mostly by improving heat and mass transfer performance of the equipment in the system, making full use of absorption heat, and improving working fluid performance. Among these directions, improving working fluid performance, especially the application possibility of NH_3/H_2O nanofluids, in which nanoparticles are suspended evenly in ammonia–water, has become a new branch of AARS field.

Since Choi (1995) proposed the concept of the nanofluid, which is a suspension of nanoparticles in a continuous and saturated liquid, it was studied in depth in many fields, especially in the engineering thermal physics. A number of results showed that nanofluid has better physical properties compared to "conventional" fluids such as water, engine oil and ethylene glycol (Chein and Huang, 2005; Daungthongsuk and Wongwises, 2007; Li and Xuan, 2002; Maïga et al., 2005, 2006; Pak and Cho, 1998; Palm et al., 2004; Roy et al., 2006). Therefore, heat transfer efficiency of heat exchanger is believed to increase too when nanofluid is applied in it (Pak and Cho, 1998). The latest review about the developments of nanofluid flow and heat transfer can be found in Kasaeian et al. (2016). In the field of trying to apply nanofluids to AARS, the results of previous researchers are as follows: Kim et al. (2006) found that the addition of nanoparticles enhances the bubble absorption performance up to 3.21 times, and under the combined action of nanoparticles and surfactants, the absorption performance increases up to 5.32 times (Kim et al., 2007). Amaris et al. (2014) investigated the passive intensification of the ammonia absorption process with $NH_3/LiNO_3$ using carbon nanotubes and advanced surfaces in a tubular bubble absorber. Their results showed that the maximum absorption mass flux achieved with the CNT binary nanofluid and the smooth tube is up to 1.64 and 1.48 times higher than reference values at cooling-water temperatures of 40 and 35 °C, respectively. It is also found that the simultaneous use of CNT nanoparticles and advanced surfaces resulted in a more pronounced increase in the absorption mass flux and solution heat transfer coefficient with respect to the smooth tube absorber with NH3/$LiNO_3$ as a working pair. Yang et al. (2011) studied the enhancement of ammonia–water falling film absorption by adding nano-particles. The results showed that effective absorption ratio increased by 70% and 50% with Fe_2O_3 and $ZnFe_2O_4$ nanofluid respectively when the initial ammonia mass fraction is 15%. The absorption enhancement by the nanofluid is attributable to the heat transfer enhancement and the decrease in viscosity of nanofluid. Ma et al. (2009) also presented the enhancement of bubble absorption process using carbon nanotubes (CNTs)–ammonia binary nanofluid. Their findings exhibited that the mass fraction of CNTs has an optimum value to the effective absorption ratio of the binary nanofluid, and the effective absorption ratio increases with the initial concentration of ammonia increasing. Li et al. (2015) found that