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International Journal of Refrigeration 29 (2006) 22–29
REVUE INTERNATIONALE DU FROID
INTERNATIONAL JOURNAL OF
refrigeration
www.elsevier.com/locate/ijrefrig

The effect of nano-particles on the bubble absorption performance in a binary nanofluid

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Received 15 April 2005; received in revised form 22 August 2005; accepted 22 August 2005
Available online 28 October 2005

Abstract

The objectives of this paper are to examine the effect of nano particles on the bubble type absorption by experiment and to find the optimal conditions to design highly effective compact absorber for NH_3/H_2O absorption system. The initial concentrations of NH_3/H_2O solution and the kinds and the concentrations of nano particles are considered as key parameters. The results show that the addition of nano particles enhances the absorption performance up to 3.21 times. Moreover, the absorption rate increases with increasing concentration of nano particles and the nano particles are more effective for lower absorption potential solution. The potential enhancement mechanism for binary nanofluid is suggested. The experimental correlations of the effective absorption ratio for each nano particles, Cu, CuO, and Al_2O_3, are suggested within $\pm 10\%$ error-band.

Keywords: Absorption system; Ammonia-water; Experiment; Fluid; Particle; Bubble

Effet des nanoparticules sur la performance d'un système à absorption à bulles utilisant un nanofluide binaire

Mots clés : Système à absorption ; Ammoniac-eau ; Expérimentation ; Fluide ; Particule ; Bulle

1. Introduction

The thermal driven absorption system is considered as the alternative to the compression system, which causes the environmental problems such as global warming and ozone layer depletion. However, the performance of the absorption system is lower than that of the compression system so it should be enhanced to be an effective alternative. Especially, the absorber is one of the most critical components in the absorption systems from the viewpoint of its size and performance. The absorber has complicated heat and mass transfer mechanism, which influences the system performance significantly [1]. Therefore, many researchers have studied how to improve the absorption performance.

The techniques for the enhancement of heat and mass transfer performance are generally categorized into three methods; the mechanical treatment, the chemical treatment and the application of nano technology [1,2]. First, the selection of heat transfer mode such as falling film type and

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doi:10.1016/j.ijrefrig.2005.08.006

Nomenclature

m	mass of the test section (g)
$\dot{m}$	absorption rate (g s^{-1})
$R_{eff,abs}$	effective absorption ratio defined by Eq. (2)
t_{abs}	vapor absorption time (s)
x	weight based concentration (%)

Subscripts

abs	absorption process
fin	final state
ini	initial state
NH₃	ammonia
NP	nano particle

bubble type, is a kind of mechanical treatment. Kang et al. [3] studied the absorption performance of NH_3/H_2O system for both falling film type and bubble type, and reported that the size of bubble absorber could be 47% smaller than that of falling film absorber. Another example for the mechanical treatment is the surface treatment of heat transfer tubes. The mechanical surface treatment can be categorized into two groups: shape treatment and roughness treatment. The shape treatment falls on the macro-scale treatment, while the roughness treatment does on the micro-scale treatment. Some literature has been found on the macro-scale treatment. The constant curvature surface tube (CCS tube) was developed to obtain a high wettability with even liquid distribution on the surface that could be realized by introducing the local constant curvature [4,5]. In the meanwhile, the micro-scale treatment such as scratching, coating and baking (oxidation) is considered to increase the wettability on the surface with low manufacturing cost. Kim et al. [6] studied the effects of micro-scale hatched tubes on the wettability by developing the quantitative wettability criterion; the method of the minimum flow rate. They reported that the wettability for the micro-scale hatched tubes was higher than that for the smooth tubes, and it decreased linearly along the vertical location in a column.

The representative chemical treatment is the addition of surface active agents into the working fluids. The addition of surfactant causes the interfacial turbulence, which leads to a higher heat and mass transfer performance [7–10]. The basic mechanism of the interfacial turbulence has been extensively investigated for several decades [11–13]. Kashiwagi [11] found that the interfacial turbulence was induced by the gradient of surface tension, which is called Marangoni convection. He also suggested that the presence of the islands of surfactant on the surface was the trigger of violent Marangoni convection. However, Hozawa et al. [12] suggested that Marangoni convection be initiated not by the islands of surfactant but by the 'salting-out' phenomenon. Kang et al. [13] compared two models by experiments, and concluded that the salting-out effect was a trigger for inducement of Marangoni convection under the surfactant solubility, while the imbalance between the surface and the interfacial tension was a trigger over the surfactant solubility. Kim et al. [14] studied the effect of chemical surfactants on the bubble type NH_3/H_2O absorption performance and reported that the addition of surfactant could enhance the absorption rate up to 4.81 times.

In recent decade, the nanofluid becomes one of the most attractive heat transfer media due to the development of nano technology. The definition of nanofluid is the solid/liquid mixture in which nano-sized particles ($d_p <$ 100 nm) are suspended evenly in the base liquid [15]. It is well known that the nanofluid can enhance the effective thermal conductivity and affects the heat transfer characteristic of fluid [15–17]. Keblinski et al. [16] studied the mechanisms of the enhancement of thermal conductivity by nanofluid. They suggested four potential mechanisms; Brownian motion of the particles, liquid layering at liquid/particle interface, nature of heat transport in nano particles, and effects of nano particle clustering. You et al. [17] carried out the pool boiling experiment with nanofluid and found that critical heat flux of nanofluid increased significantly.

In this study, the combined effect of mechanical treatment and nanofluid for NH_3/H_2O absorber is considered. For the mechanical treatment, the bubble type absorption is selected as the absorption mode, and the nano particles are added to the working fluid for the nano technology application. Because the solution of the absorption system is a binary mixture and the nanofluid is considered as a single phase fluid by the definition, the absorption medium with nano particles is named as the 'binary nanofluid' in this paper.

To the best of our knowledge, the studies on the effect of nanofluid on the mass transfer performance have not been conducted although many researchers have actively carried out to study the heat transfer enhancement by nanofluid. However, in the slurry or colloidal system, the effects of milli or micro particles on the absorption performance have been studied. Kars et al. [18] studied the gas absorption in slurries with active carbon in water and explained the mechanism of the improvement of the absorption rate. The particles in the liquid media move to the film layer of concentration boundary, adsorb the gas, and then desorb the gas in the bulk liquid. This phenomenon can increase the absorption rate and is called as 'the grazing effect'. Zhou et al. [19] reviewed the effect of fine particles on multiphase mass transfer and concluded that the finer the particles were, the stronger the influence was.

The objectives of this paper are to examine the effect of nanofluid on the bubble absorption and to find the optimal