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Experimental study on enhancement of falling film absorption process by adding various nanoparticles

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ABSTRACT

Absorption air conditioning system containing no chlorofluorocarbons is considered environmentally friendly and a competitive alternative to conventional vapor compression air conditioning system. One of the most commonly used refrigeration working pair is LiBr/H_2O. This paper experimentally studies the falling film absorption of LiBr/H_2O with various kinds of nanoparticles dispersed, such as Cu, Al_2O_3 and CNT. The results show that the variety, mass fraction and size of nanoparticles, as well as solution flow rate are considered as the key parameters. The smaller the nanoparticles size, the better the effective absorption ratio. The larger the nanoparticles mass fraction, the better the effective absorption ratio. The best enhancement is achieved by adding Cu nanoparticles for all the studied nanoparticles species. The effective absorption ratios for all the studied cases are higher than 1.0, which proves that the dispersed nanoparticles have positive effects on the absorption process.

1. Introduction

The increase of electricity cost and environmental problems have made the absorption refrigeration technology more attractive for both residential and industrial applications. Absorption chillers are widely used in the air-conditioning industry, because they can be activated by hot water, steam and direct-fired natural gas instead of electricity [1,2]. Due to its use of solar energy and waste heat recovery, absorption refrigerating system is an environment-friendly alternative to conventional vapor compression refrigerating system which also saves energy [3]. It is desirable to increase the efficiency of absorption devices used in the absorption chillers/heat pump. Since in case of such an improvement, it becomes possible to reduce the size of absorption chiller/heat pump and decrease its operating costs. Therefore, significant efforts have been devoted to enhance the performance of absorption process.

Improving the heat and mass transfer performance is a critical issue in the development of energy-efficient heat and mass transfer fluids that are required in many industrial applications. Nanofluids are fluids filled with stably distributed solid particles of 100 nm or less which enhance the effective thermal conductivity of the original fluid [4–7]. The suspended ultrafine particles are expected to improve the heat and mass transfer performance of the fluid. Much research on the enhancing heat transfer of nanofluids, both experimentally and theoretically, has been conducted [8–12]. A CFD model of a horizontal circular tube was presented by Moghadassi, et al. [13] to investigate the effect of nanofluids on laminar forced convective heat transfer, which indicated a higher convective heat transfer coefficient for the hybrid nanofluids. For the studied hybrid nanofluids, the average Nusselt number increased 13.46% in comparison to pure water. Sun, et al. [14] studied fluid flow and heat transfer in plate heat exchangers and concluded that nanofluids enhance the heat transfer performance of the heat exchangers. Tohidi, et al. [15] found that laminar flow thermal performance can be enhanced by combining nanofluids and chaotic convection. It is expected that the nanofluids could be applied as an advanced heat transfer fluid for thermal engineering.

Studies have indicated that nanoparticles not only improve heat transfer but can also enhance mass transfer of nanofluids. Khanolkar and Suresh [16] studied the enhanced mass transfer rates in nanofluids by experiments and modeling. SiO_2 and TiO_2 nanofluids have been researched for their effect on the rate of gas-liquid mass transfer, using a capillary tube apparatus. The results show that enhancement of up to 165% in the mass transfer coefficients was observed at fairly low volume fractions of the nanoparticles. Kang, et al. [17] examined the effects of the addition of nanoparticles (Fe nanoparticles and carbon nanotubes, CNT) to a falling film of LiBr aqueous solution on vapor absorption and heat transfer rates. It was found that nanoparticles enhance not only the heat transfer rates but also the vapor absorption

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Nomenclature

c_{in}	Inlet concentration of solution (wt% LiBr)
c_{out}	Outlet concentration of solution (wt% LiBr)
Δc	Solution concentration difference between inlet and outlet (wt% LiBr)
d_p	Nanoparticle size (nm)
m_w	Water vapor absorption rate ($kg\,h^{-1}$)
m_{wb}	Water vapor absorption rate of basefluids ($kg\,h^{-1}$)
m_{wn}	Water vapor absorption rate of nanofluids ($kg\,h^{-1}$)
R_{eff}	Effective absorption ratio
ν_{in}	Inlet volume flow rate of solution ($L\,h^{-1}$)
ρ_{in}	Inlet density of solution ($g\,cm^{-3}$)
φ	Nanoparticles mass fraction (wt%)

rates. Using 0.02 vol% of Al_2O_3 nanoparticles in pool type absorption, Lee, et al. [18] reported 29% and 18% enhancements in heat transfer and absorption rates, respectively. Yang, et al. [19] observed significant enhancement of the effective absorption ratio with the addition of Fe_2O_3 and $ZnFe_2O_4$ nanoparticles in ammonia-water. This mass transfer enhancement was attributed to the increase in heat transfer rate and the decrease in the viscosity of the nanofluids. Mass transfer enhancements with the additions of nanoparticles were also reported by other researchers. The effects of nanofluid parameters on the local dimensionless heat and mass transfer rates in power-law nanofluids over a stretching surface with convective boundary condition were investigated by Khan and Gorla [20].

Although most experimental studies have confirmed that the nanoparticles have a positive role on enhancing heat and mass transfer, there is also some controversy and ambiguity in the scientific literature for nanoparticles enhancement of heat and mass transfer [21]. Therefore, it is necessary to clarify the nanoparticles enhancement and associated Brownian motion effect by further experimental study.

In this paper, the mass transfer performance of $LiBr/H_2O$ nanofluids with various nanoparticles, namely, Al_2O_3, Cu and CNT, were studied by experimental investigation. The objectives are to explore the effects of key parameters such as the types of nanoparticles, nanoparticles mass fraction and size on the performance of falling film absorption process, aiming to obtain the optimum conditions of using $LiBr/H_2O$ nanofluids.

2. Preparation of nanofluids

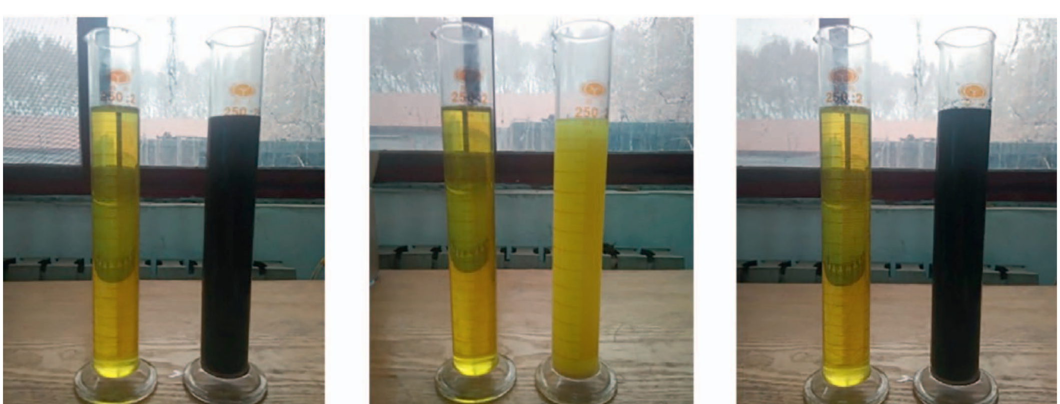
Three different nanofluids were obtained by dispersing Cu, Al_2O_3 and CNT into $LiBr/H_2O$ solution, respectively. In this experiment, preparing the nanofluids takes the following steps: firstly, mixed a certain amount of nanoparticles into $LiBr/H_2O$ basefluid, which mass fraction is 57%, and stirred mechanically well; secondly, exerted ultrosonic vibration on the mixing solution sequentially with the ultrasonic oscillator about 3 h to get the stable nanoparticle suspension of $LiBr/H_2O$ solution; and then, cooled the nanofluids to about 290 K inside the refrigerator. Fig. 1 (a), (b) and (c) shows the $LiBr/H_2O$ nanofluids appearance of the Cu, Al_2O_3 and CNT after standing 24 h with basefluid. The SEM images of Cu, Al_2O_3 and CNT nanoparticles are shown in Fig. 2. The nanoparticles of Cu and Al_2O_3 are spherical or analogously spherical and the purity is higher than 99.9%. There are three different sizes of Cu nanoparticles (around 50, 80 and 100 nm) and Al_2O_3 nanoparticles (around 25, 50 and 100 nm). The purity of Mutiwall Carbon Nanotubes (MWCNT) is higher than 95%. Its innerer diameter, outer diameter and length are 5–10, 20–40 nm and 10–30 μm, respectively.

3. Experimental system and procedures

The schematic diagram of the experimental system for $LiBr/H_2O$ nanofluids falling film absorption is shown in Fig. 3. The unit is mainly composed of an absorber (1), a steam generator (2), two solution containers (3, 4), a vacuum pump (5), measuring devices (6, 7), several valves (8) and pipelines. The absorber is the core device of the setup, in which the nanofluids falling film along the distributing liquid plate absorbed the water vapor from the vapor generator. $LiBr/H_2O$ nanofluids is sucked to liquid distributor from the concentrated liquid container (3) under differential pressure and flow along falling film plate. The materials of the end cover and body of absorber are stainless steel and plexiglass separately, thus the process of falling film flowing is visible. The falling film absorber is a cylinder with height of 1100 mm and inner diameter of 300 mm, consists of two end covers and liquid distributor. The liquid distributor is made of a balanced slot and stainless steel plate which height and width are 500 mm and 200 mm, respectively.

The wettability of falling flim on the plate is an important variable. In order to ensure a good wettability, several measures had been taken in the experiment. A liquid distributor is installed at the top of the absorber. It is a kind of reservoir slot, in which the initial liquid overflowing the edge forms a certain liquid level for the purpose of maintaining a stable falling film. The concrete structure and operating principle can be seen Zhang et al. [22].

The experiments were performed using the following procedures: 1) start the vacuum pump and the vacuum pressure transmitter. The



(a) Cu (b) Al_2O_3 (c) CNT

Fig. 1. Comparison between the basefluid and nanofluids after 24 h static storage.