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Heat and mass transfer enhancement of binary nanofluids for H_2O/LiBr falling film absorption process

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ABSTRACT

The objectives of this study are to measure the vapor absorption rate and heat transfer rate for falling film flow of binary nanofluids, and to compare the enhancement of heat transfer and mass transfer under the same conditions of nanofluids. The key parameters are the base fluid concentration of LiBr, the concentration of nanoparticles in weight %, and nanoparticle constituents. The binary nanofluids are H_2O/LiBr solution with nanoparticles of Fe and Carbon nanotubes (CNT) with the concentrations of 0.0, 0.01 and 0.1 wt %. The vapor absorption rate increases with increasing the solution mass flow rate and the concentration of Fe and CNT nanoparticles. It is found that the mass transfer enhancement is much more significant than the heat transfer enhancement in the binary nanofluids with Fe and CNT. It is also found that the mass transfer enhancement from the CNT nanoparticles becomes higher than that from the Fe nanoparticles. Therefore, the CNT is a better candidate than Fe nanoparticles for absorption performance enhancement in H_2O/LiBr absorption system.

Amélioration du transfert de chaleur et de masse pour les nanofluides binaires dans les procédés à absorption par film tombant au LiBr/H_2O

Mots clés : Système à absorption ; Eau-bromure de lithium ; Amélioration ; Absorption ; Film tombant ; Additif ; Particule ; Transfert de chaleur ; Transfert de masse

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Nomenclature

CNT	carbon nanotube
C_p	specific heat [kJ kg^{-1} K^{-1}]
H	enthalpy [kJ kg^{-1}]
$\dot{m}$	mass flow rate [kgs^{-1}]
$\Delta\dot{m}_{abs}$	absorption rate [kg s^{-1}]
Q	heat transfer rate [kW]
x	concentration of LiBr [%]

Subscripts

abs	absorption
b	base fluid
c	coolant
in	inlet
0	reference
out	outlet
n	nanoparticles
sol	solution
v	vapor

1. Introduction

Recently, many studies on nanofluids have been carried out actively. Nanofluid is defined as a fluid in which nanoparticles below 100 nm in diameter are stably suspended in the base fluid. The binary nanofluid is defined as the nanofluid in which the base fluid is a binary mixture such as ammonia/water (Kim et al., 2006). Nanofluid can not only solve the problems such as sedimentation, cohesion and corrosion which happen conventionally in heterogeneous solid/liquid mixture with milli-sized or micro-sized particles, but also increase the thermal performance of base fluids remarkably. Research on the nanofluids are categorized into five groups: (1) stability analysis and experiments; (2) property measurement such as thermal conductivity and viscosity; (3) convective and boiling heat transfer; (4) mass transfer in binary nanofluids; and (5) theoretical analysis and model development. This paper will focus on the topics of property measurement, convective heat transfer and mass transfer enhancement.

Choi (1995) reported that the enhancement of the thermal conductivity of base fluid reached up to 40% by adding a little amount of nanoparticles and nanotubes. To explain Choi's experimental results, Keblinski et al. (2002) examined the potential mechanisms for thermal conductivity enhancement such as Brownian motion, liquid layering and nano-particle clustering. Eastman et al. (2001) measured the effective thermal conductivity of ethylene glycol-based nanofluids containing Cu nanoparticles by the transient hot-wire method, and found that the effective thermal conductivity increased up to 40% for 0.3 vol.% Cu nanoparticles of mean diameter less than 10 nm. Prasher et al. (2006) suggested that the convection caused by the Brownian movement of the nanoparticles was primarily responsible for the observed enhancement in the effective thermal conductivity of nanofluids and proposed a Brownian motion based convective–conductive model through an order-of-magnitude analysis. Prasher et al. (2001) also proposed that the thermal conductivity of nanofluids could be significantly enhanced as a result of aggregation of the nanoparticles. As mentioned by Das et al. (2006), however, the mechanism of thermal conductivity enhancement is still unclear.

Ding et al. (2005) observed significant enhancement of the convective heat transfer in CNT nanofluids, and found that the enhancement depended on the flow condition, CNT concentration and the pH level, and the effect of pH was to be small. To explain the significant enhancement, they also proposed possible mechanisms such as particle re-arrangement, shear induced thermal conduction enhancement, reduction of thermal boundary later thickness due to the presence of nanoparticles as well as the high aspect ratio of CNT. Heris et al. (2006) measured laminar flow convective heat transfer of oxide nanofluids containing CuO and Al_2O_3 nanoparticles under the constant wall temperature boundary condition. They found that for both nanofluid systems heat transfer coefficient enhanced with increasing nanoparticles concentrations as well as Peclet number and the Al_2O_3/water nanofluids showed more enhancement compared with CuO/water. Buongiorno (2006) considered seven slip mechanisms of convective transport in nanofluids: inertia, Brownian diffusion, thermophoresis, diffusiophoresis, Magnus effect, fluid drainage, and gravity, and concluded that, of these seven, only Brownian diffusion and thermophoresis were important slip mechanisms in nanofluids. The author proposed an alternative explanation for the abnormal heat transfer coefficient increase; the nanofluid properties might vary significantly within the boundary layer because of the effect of the temperature gradient and the thermophoresis. Lee and Mudawar (2007) made an assessment for the effectiveness of nanofluids for single-phase and two-phase heat transfer in micro-channels, and found that the high effective thermal conductivity of nanofluids enhanced the single-phase heat transfer coefficient for fully-developed laminar flow, but the enhancement was far weaker for turbulent flow because of a weaker dependence of the heat transfer coefficient on thermal conductivity as well as decreased specific heat and increased viscosity.

Although many studies have conducted to study the thermal conductivity and heat transfer enhancement in nanofluids, the studies for the mass transfer characteristics of nanofluids have not found in the literature. Several researches have studied the mass transfer enhancement of the colloid with the particles of milli- or micro-size. Vinke et al. (1993) reported that the hydrogen absorption rate into an aqueous solution was enhanced by the presence of fine particles. According to the reports by Alper et al. (1980), Kars et al. (1979), and Quicker et al. (1987), the enhancement of the gas-absorption rate in the colloid is caused by the grazing effect. The grazing effect is the transfer phenomenon of a gas from the gas–liquid interface to the bulk of the liquid. Recently, Kim et al. (2006) defined binary nanofluid as the binary mixture in which nanoparticles were evenly distributed and studied the effect of binary nanofluid on the ammonia bubble absorption performance.

Even though many studies have been found on the thermal conductivity and convective heat transfer enhancement in nanofluids, the experimental results are quite different from each other because the heat transfer characteristics of nanofluids strongly depend on the thermal properties of the base