The Effect of Binary Nanofluids and Chemical Surfactants on the Absorption Performance

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ABSTRACT

The objectives of this paper are to visualize the bubble behavior in the ammonia/water absorption and to study the effect of nanoparticles and surfactants on the absorption characteristics. Binary nanofluid which means binary mixture with nano sized particles is tested to apply nanofluid to the absorption system. Cu, CuO and Al_2O_3 nanoparticles are added to make the binary nanofluids into ammonia/water solution, and 2-Ethyl-1-Hexanol, n-octanol and 2-octanol are used as the surfactants. The concentration of ammonia in the basefluid, that of nanoparticles in the nanofluid, and that of surfactants in the nanofluid are considered as the key parameters. The results show that the addition of surfactants and nanoparticles improves the absorption performance up to 5.32 times. It can be concluded that the addition of surfactants and the application of binary nanofluid enhance significantly the absorption performance during the ammonia bubble absorption process.

1. INTRODUCTION

The absorber, in which heat and mass transport phenomena occur simultaneously, is one of the most critical components in the absorption system. It has the most significant influence on the performance and the size of the absorption system. In order to improve the performance of the absorber, many studies have been carried out actively. The absorption enhancement techniques are categorized into three methods: the mechanical treatment, the chemical treatment, and nanotechnology (Kang et al. 2003). The flow patterns, such as falling film type and bubble type, can be considered mechanical treatment. Kang et al. (2000) compared the absorption performance of ammonia/water system for both falling film type and bubble type, and reported that the absorber of bubble type could have about 48.7% smaller size than that of falling film type.

The representative chemical treatment is the addition of surfactant into the working fluid. Some literature has been found on the effect of surfactant on the heat and mass transfer performance. Kashiwagi (1988) reported that the addition of surfactant induced the Marangoni convection that activated the turbulent movement at the interface. Möller et al. (1996) investigated the influence of surfactants on the absorption of ammonia into water. Kang et al. (1999) visualized Marangoni convection using the shadow graphic method, and proposed a new model for Marangoni convection during the ammonia/water absorption process. Kim et al. (2006) studied the effect of surfactant on the ammonia bubble absorption performance.

Nano technology can be applied to absorption system to enhance the heat and mass transfer performance. Recently, due to the development of nanotechnology and surface science, many researches 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 basefluid. It can not only solve the problems such as sedimentation, cohesion and corrosion which happen conventionally in heterogeneous solid/liquid mixture with millimeter or micrometer particles, but also increase the thermal performance of basefluids remarkably. Choi (1995) reported that the enhancement of the thermal conductivity of basefluid reached up to 40% by adding a little amount of nanoparticles and nanotubes. To explain Choi's experimental results, Keblinski et al. (2002) suggested the potential mechanisms for thermal conductivity enhancement such as Brownian motion, liquid layering and nanoparticle clustering. Moreover, You et al. (2003) reported that the critical heat flux in pool boiling of Al_2O_3 nanofluids increased dramatically (about 200%) compared to the pure water case. Recently, Kim et al. (2004) studied the convective instability driven by buoyancy and the heat transfer characteristics of nanofluids.

Although many studies have conducted to study the heat transfer enhancement in nanofluid, the studies for the mass transfer characteristics by nanofluid are immaterial. 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. Kim et al. (2006) defined binary nanofluid as the binary mixture in which nano-particles are evenly distributed and studied the effect of binary nanofluid on the ammonia bubble absorption performance. The objectives of this paper are to study the mass transfer enhancement of NH3/H2O absorption, to investigate the combined effect of nanoparticles and surfactants on the absorption characteristic, and to find the optimal conditions of nanofluids and surfactants.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

2.1 Experimental Apparatus

In order to study the effects of nanoparticles and surfactants on the absorption performance, the effective absorption ratio for each condition is empirically measured in the test section. During the absorption process, the ammonia bubble behavior is visualized by using the shadowgraph method. Figure 1 shows the schematic diagram of the visualization apparatus.

2.2 Experimental Procedure

The geometric details of test section and the experimental conditions are summarized in Table 1. 2-Ethyl-1-Hexanol, n-octanol, and 2-octanol are used as the surfactants and nano sized Cu, CuO, and Al_2O_3 particles are added into a binary mixture of NH_3/H_2O to make the binary nanofluids. The binary nanofluid is prepared by the ultrasonic vibrator for the stable dispersion of nanoparticles. A binary nanofluid(NH_3/H_2O+ nanoparticles) is filled in the test section, and measured the initial weight of the test section with binary nanofluid (m_i). The ammonia gas is injected into the binary nanofluids for 2 minutes. The NH_3 bubbles are generated in the orifice at the bottom of test section and freely rise up. They are absorbed into the binary nanofluid during the rising of the bubbles. The amount of NH_3 absorption is measured by a precise electronic balance (m_f), and the absorption process is observed by a high speed camera with 200 frame/sec.

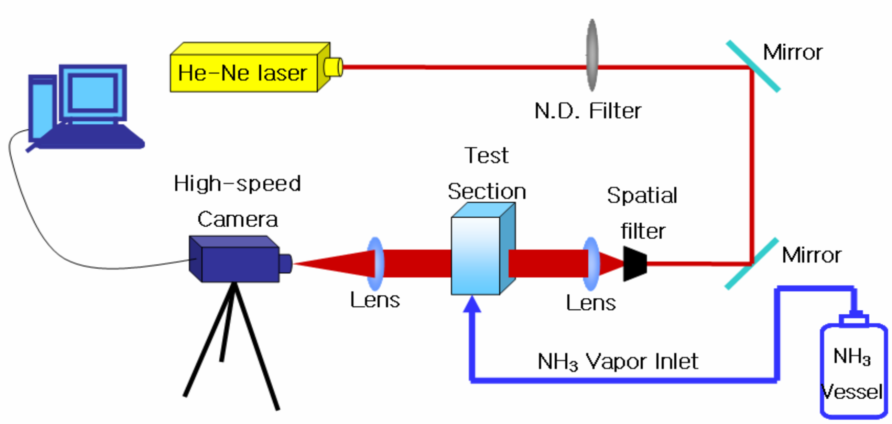

Figure 1 : Schematic Diagram of Visualization Apparatus

Table 1 : Geometric and Experimental Conditions

Vapor concentration		99.999%
Solution temperature		20 °C
Pressure		0.1 MPa
Solution concentration		0 ~ 18.7%
Surfactant	Kinds	2-Ethyl-1-Hexanol n-Ocatanol 2-Octanol
	Concentrations	0, 100, 500, 700, 1000 ppm
Nanofluid	Kinds	Cu, CuO, Al_2O_3
	Size of nanoparticle	Under 50 nm
	Weight percent	0, 0.01, 0.05, 0.1%
Test section width		20 mm
Test section length		20 mm
Test section height		200 mm
Orifice diameter		2 mm

3. DATA REDUCTION

To quantify the absorption performance for each experimental condition, the absorption rate is defined as Equation (1).

$$\dot{m}_{abs} = \frac{m_f - m_i}{\Delta t} \tag{1}$$

where m_f is the final mass of test section after the absorption process, m_i is the initial mass of test section before absorption process and Δt is the absorption time elapsed.

In order to express the effect of nanoparticles on the absorption rate, an effective absorption ratio is defined as follows:

$$R_{eff} = \frac{\dot{m}_{nf,abs}}{\dot{m}_{bf,abs}} \tag{2}$$

where the subscripts nf and bf denote nanofluid and basefluid, respectively. The physical meaning of the effective absorption ratio is the enhancement of potential absorption rate by adding the nanoparticles, in other word, the effectiveness of nanoparticles.

4. RESULTS AND DISCUSSION

4.1 The Addition of Chemical Surfactants

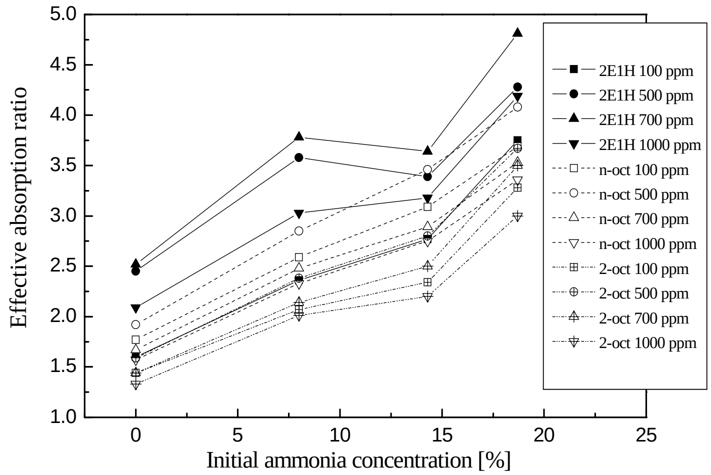

Figure 2 : The Effective Absorption Ratio for the addition of Surfactants

In order to investigate the effect of surfactants on the absorption performance quantitatively, the effective absorption ratio is calculated from Equation (2). Figure 2 shows the effective absorption ratios with respect to the initial ammonia concentration of solution for each surfactant. In all cases with surfactants, the effective absorption ratio is higher than 1.0, so it can be said that the addition of surfactant enhances the absorption performance. As shown in this graph, it is found that 2E1H is the most effective out of considered surfactants, and the effective absorption ratio for n-octanol is higher than for with 2-octanol. The effective absorption ratio increases with increasing the initial ammonia concentration. This means that the addition of surfactant becomes more effective at a lower absorption potential range.

4.2 Absorption Performance in Binary Nanofluids

Figure 3 shows the effective absorption ratio with respect to the weight percents of Cu, CuO, and Al_2O_3 nanoparticles. Since the effective absorption ratios for all binary nanofluids are higher than 1.0, it clearly implies that the binary nanofluids can enhance the absorption performance. As the weight percent of nanoparticles increases, the effective absorption ratio increases almost linearly. The maximum effective absorption ratio becomes 3.21 in the case of ammonia 18.7% binary nanofluid with 0.1% Cu nanoparticles. The effective absorption ratios for all binary nanofluids with respect to the ammonia concentration are presented in Fig. 3. This graph reveals that the effective absorption ratio increases with increasing ammonia concentration. That is, the lower the absorption potential is, the more significant the effect of nanoparticles becomes.

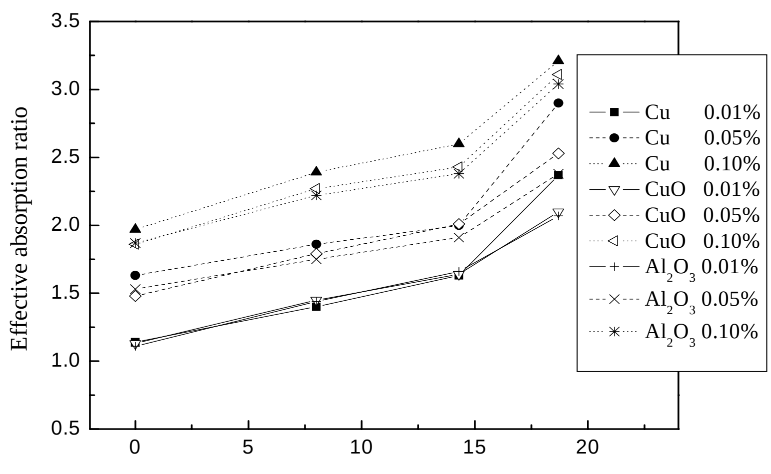

Figure 3 : The Effective Absorption Ratio for the addition of Nanoparticles

Figure 4 : The bubble absorption behavior in the copper 0.1% binary nanofluid

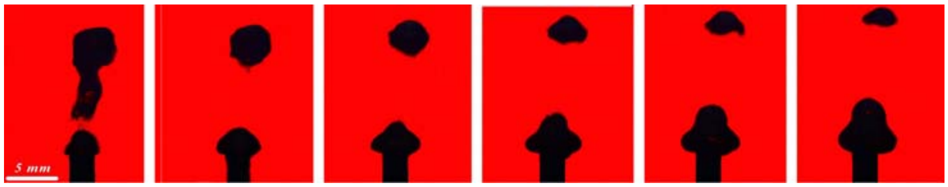

Figure 5 : The bubble absorption behavior in the copper 0.1% binary nanofluid with 2-ethyl-1-hexanol 700ppm

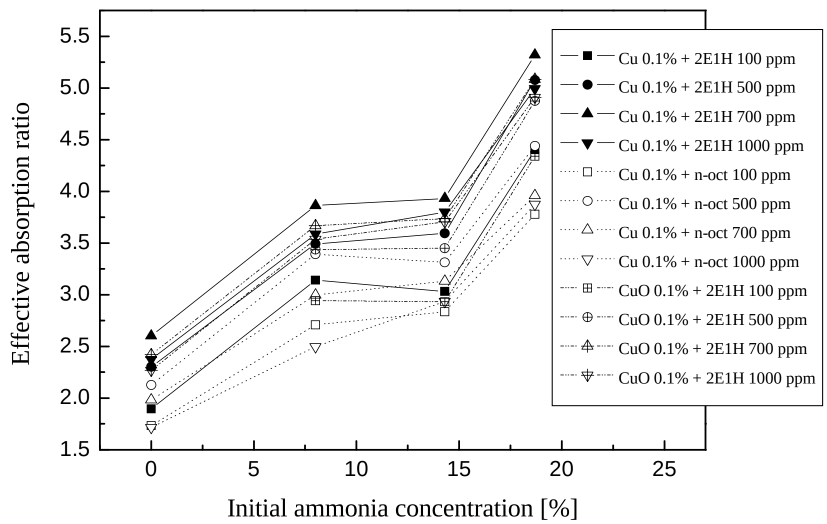

Figure 6 : The Effective Absorption Ratio for the Binary Nanofluids with Surfactants

4.3 The Effects of Binary Nanofluids with Chemical Surfactants

The shadowgraph images of the bubble behavior during the absorption process in the Cu 0.1% binary nanofluid and the Cu binary nanofluid with 2E1H are presented in Figs. 4 and 5, respectively. In the figure 5, the bubble shape is distorted and the former bubble is coalesced with the next bubble.

Figure 6 shows the effective absorption ratio for the binary nanofluid with chemical with respect to the initial ammonia concentration of binary nanofluid. The maximum effective absorption ratio is 5.32 in the case of ammonia 18.7%, Cu 0.1% binary nanofluid with 2E1H 700 ppm. Therefore, it can be concluded that the application of binary nanofluid with chemical surfactant is the best way among the considered enhancement techniques in the viewpoint of the effectiveness.

From the previous studies, Kim et al. (2006) suggested the experimental correlations of the effective absorption ratio for the surfactant addition and for the binary nanofluid. The generic forms of correlations for the surfactant addition and for the binary nanofluid are as Equations (3) and (4), respectively. The suggested coefficients for the surfactant addition and for the binary nanofluid are summarized in Tables 2 and 3, respectively.

$$
\begin{aligned}
R_{eff,sur} = {} & (a0 + a1 \times x_{NH_3} + a2 \times x_{NH_3}^2) \\
& + (b0 + b1 \times x_{NH_3} + b2 \times x_{NH_3}^2) \times x_{Sur} \\
& + (c0 + c1 \times x_{NH_3} + c2 \times x_{NH_3}^2) \times x_{Sur}^2
\end{aligned}
\tag{3}
$$

Table 2 : Coefficients of correlation for the surfactant

Coeffi-cients	2-ethyl-1-hexanol	n-octanol	2-octanol
a0	1.825	1.917	1.442
a1	7.913	8.778	5.861
a2	12.458	9.720	11.441
b0	701.338	-291.276	74.897
b1	44.708	-4.426	6283.942
b2	-2416.16	-5389.5	31177.32
c0	55.704	11.224	6460.167
c1	16988.06	10620.75	-1.24298E+07
c2	-80.475	14.059	5248.614

$$R_{eff,bn} = (p0 + p1 \times x_{NH_3} + p2 \times x_{NH_3}^2) + (q0 + q1 \times x_{NH_3} + q2 \times x_{NH_3}^2) \times x_{NP} \tag{4}$$

Table 3 : Coefficients of correlation for the binary nanofluid

Coefficients	Copper	Copper oxide	Aluminum oxide
p0	1.125	1.072	1.067
p1	-0.035	0.014	0.018
p2	0.005	0.002	0.001
q0	9.092	8.248	8.522
q1	0.433	-0.048	-0.196
q2	-0.023	0.01	0.016

By nonlinear multiplication of these two correlations, the experimental correlation for the combined treatments is developed in this study. The generic form of the combined correlation is shown in Equation (5) and the calculated coefficients for the combined correlation are summarized in Table 4.

$$R_{eff,comb} = \xi 0 \times R_{eff,sur}^{\xi 1} \times R_{eff,bn}^{\xi 2} \tag{5}$$

As shown in Fig. 7, this correlation involves the experimental data within ±15% error bands.

Table 4 : Coefficients of correlation for the binary nanofluid with the surfactant

Coefficients	Copper 0.1% with 2-ethyl-1-hexanol	Copper 0.1% with n-octanol	Copper oxide 0.1% with 2-ethyl-1-hexanol
$\xi\ 0$	0.921	0.963	0.902
$\xi\ 1$	0.952	0.546	0.966
$\xi\ 2$	0.261	0.613	0.237

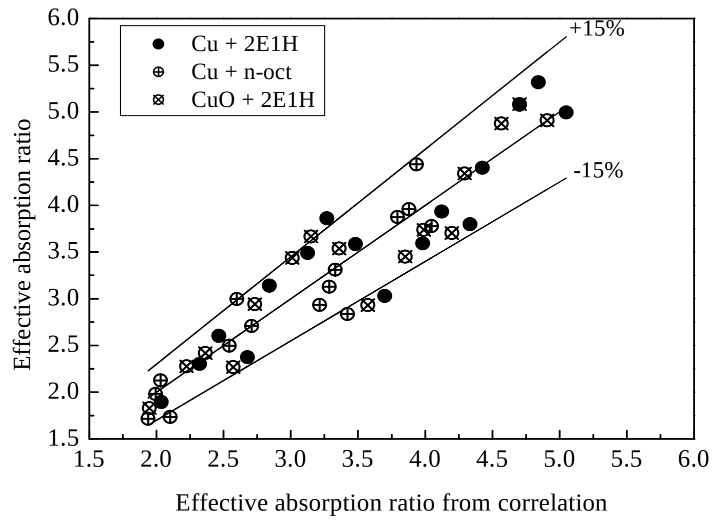

Figure 7 : The experimental correlation of the effective absorption ratio

for the binary nanofluids with surfactants

5. CONCLUSIONS

This paper studied the enhancement of mass transfer performance in the binary nanofluids and the effect of surfactant and nanoparticles on the mass transfer characteristics during NH_3/H_2O absorption process. The following conclusions are drawn from the present work.

1. The absorption performance of NH_3/H_2O with a surfactant (700 ppm of 2E1H) is enhanced up to 4.8 times in comparison with that without surfactant. For the binary nanofluid with 0.1 wt% Cu nanoparticles, it is enhanced up to 3.21 times. Furthermore, the absorption performance with both 2-Ethyl-1-Hexanol and Cu nanoparticles is improved up to 5.32 times.

2. The effective absorption ratio increases with increasing the initial ammonia concentration. It implies that the nanoparticles and surfactant have more significant effects on the mass transfer performance in the higher NH_3 concentration ranges than that in the lower concentration ranges.

3. The absorption performance can be improved by adding both surfactant and nanoparticles. The combined treatment with surfactant and nanoparticles is recommended to improve the absorption performance for practical applications.

NOMENCLATURE

d	diameter	(mm)
L	length	(mm)
m	mass	(kg)
$\dot{m}$	mass flow rate	(kg/min)
R	absorption ratio	
t	time	(min)
W	width	(mm)
Z	height	(mm)

Subscripts

abs	absorption
bf	basefluid
eff	effective
nf	nanofluid
o	orifice
TS	test section

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