Mass Transfer Enhancement of Nanofluids in a Closed System

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Introduction

Nanofluids are newly developed by uniformly dispersing nano-sized solid particles in a base fluid. It has the better physical properties than the conventional fluids [1]. Particularly, nanofluids have a high thermal conductivity, and there have been many attempts to improve the heat transfer performance and heat capacity of the cooling and heating system by adding nanoparticles to the refrigerant [2]. To apply the nanofluids to actual systems, it is necessary to clarify the performance enhancement mechanisms and the prediction models. In the field of heat transfer, many experimental data have already been obtained sufficiently.

Nanofluids improve not only the heat transfer performance but also the mass transfer performance [3]. Among the CO₂ capture methods, the physical absorption method is advantageous in that the CO₂ absorption facility cost is very low and the operation stability is good. However, according to the Henry's law, it must operate at very low temperatures (−40°C) to achieve the desired absorption rate. Research has been actively carried out to increase the absorption performance of CO₂ through nanofluids containing nanoparticles such as Al₂O₃ and SiO₂ in the methanol. Under the optimum conditions, the absorption rate is improved by more than 10%, and the regeneration performance is improved by 20% [4]. However, the mechanism for the performance enhancement has not been clarified by experiments. Mechanisms and predictive models for mass transfer enhancement are essential for practical applications. Therefore, in this study, we try to visualize the mass transfer phenomena during methanol-based nanofluid and CO₂ absorption processing by using the Schlieren technique [5]. Based on this, the fundamental mechanism of mass transfer enhancement is established.

Experimental method

Nanofluids are prepared by the two step method. Al₂O₃ (50 nm) and SiO₂ (10-20 nm) nanopowder are used. Nanopowder is added to the base fluid, methanol, and nanofluids are prepared by the ultrasonication method. The experimental conditions are summarized in Table 1. Schlieren method is used to analyze the diffusion phenomenon between CO₂ and nanofluid. A schematic diagram of the Schlieren method is shown in Figure 1. Prior to the experiment, the nanofluid is filled in the lower part of the closed section, and then CO₂ gas is injected from the upper part. Immediately after the injection, nanofluids occupy a same volume for all cases. However, as time elapse, diffusion takes place and methanol rises. The visualization method is as follows. The light from the source reaches the condensing lens, and the parallel light travels to convex mirror. The light passes through the test section and reaches the other convex mirror. After that, it passes through the knife edge, and reaches the camera.

Results and discussion

The experiments are carried out by changing the concentration of nanoparticles. The results are shown in Figure 2. The horizontal axis represents the elapse time in seconds, and the vertical axis represents the concentration of the nanofluid in volume fraction. 0 means pure methanol. Both Al₂O₃ and SiO₂ nanofluids show a similar diffusion tendency, and the diffusion of nanofluids is faster than that of pure methanol. When the concentration of the nanoparticles is 0.01 vol%, the mass transfer rate is remarkably faster than 0.005 vol%. However, the mass transfer rate decreases again as the concentration increases higher than 0.01 vol%. To analyze the visualization results quantitatively, we calculated the occupied area of nanofluid over time by pixel analysis of the image. Figure 3 shows the improvement in the mass transfer rate of nanofluids versus pure methanol. When the concentration of the nanoparticles is 0.01 vol%, the improvement of the mass transfer rate
is the highest.

In the Schlieren experiment (Fig. 2), the interface of CO$_2$/nanofluid becomes more concave compared to CO$_2$/methanol. It is that the surface tension plays an important role in the variation of interface configuration. However, there is no significant difference of surface tension between the pure methanol and the nanofluid [6]. At the concentration of nanofluid with 0.01 vol%, the interface is curved to the innermost, and when the concentration is lower or larger, it becomes flatter.

![Figure 2. CO$_2$/nanofluid diffusion visualization.](image)

**Figure 2. CO$_2$/nanofluid diffusion visualization.**

Conclusions

Al$_2$O$_3$/methanol and SiO$_2$/methanol are prepared by the two step method. Al$_2$O$_3$ nanopowder and SiO$_2$ nanopowder are 15 nm and 50 nm, respectively. The nanoparticles are added and dispersed by the ultrasonication process. The mass transfer phenomenon of CO$_2$/nanofluid is visualized through the Schlieren method. It is concluded that Al$_2$O$_3$ and SiO$_2$ nanofluids show the highest mass transfer rate when the concentration is 0.01 vol%.

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References


The nanoparticles themselves do not absorb CO$_2$ gas, but they promote mass transfer by a specific action. As CO$_2$ moves from the interface to the bulk, it passes through the nanoparticles. The nanoparticles then generate the convection motion within the bulk to promote diffusion of CO$_2$. The faster the mass transfer into the bulk, the greater the difference in concentration between the bulk and the CO$_2$/nanofluid interface. In other words, a larger mass transfer potential is applied to the surface and the surface area becomes widened. As the number of nanoparticles increases to the certain level, the convection effect increases, and the mass transfer becomes faster. However, if the concentration is increased above a certain level, mass transfer performance is deteriorated. The reason is that if the nanoparticles become too much, they interfere with the diffusion path of the CO$_2$ molecule.