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Combined CO_2 absorption/regeneration performance enhancement by using nanoabsorbents

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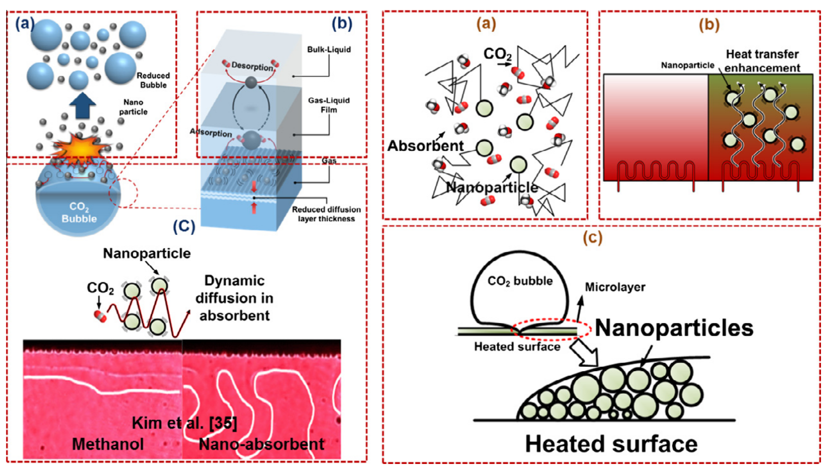
HIGHLIGHTS

- CO_2 absorption/regeneration performance enhancement by using nanoabsorbents is evaluated.
- SiO_2/methanol nanoabsorbent is more appropriate than Al_2O_3/methanol nanoabsorbent.
- The regeneration rate of SiO_2/methanol nano-absorbent is improved by 22%.
- The surface effect is more dominant than the thermal effect of the nanoparticle.

GRAPHICAL ABSTRACT

Mechanisms of CO_2 absorption and regeneration enhancement by nanoabsorbents.



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ABSTRACT

The reduction of in the emissions of CO_2, which is the representative greenhouse gas, is actively investigated worldwide because of its contribution to global warming. Energy generation processes involving the gasification of fossil fuels separate the constituent gases before combustion occurs, rendering the capture of CO_2 more attainable. Generally, CO_2 is captured through an absorption method by using a liquid absorbent in large scale gasification systems. According to Henry's solubility law, the absorption and regeneration processes should be operated at low and high temperatures respectively, and these require high energy consumption. As a solution, nanoparticles are added to the absorbent (methanol) to reduce energy consumption required in the absorption and regeneration processes. In this study, the absorption/regeneration performance was evaluated through a lab-scale combined CO_2-absorption/regeneration system. The nanoparticles used are SiO_2 and Al_2O_3, which are added at a 0.01 vol% concentration. In the case of the Al_2O_3/methanol nanoabsorbent, the performance decreases as the number of cycle increases, whereas the performance is improved steadily in the case of the SiO_2/methanol nanoabsorbent. Thus, the SiO_2 nanoparticles are more suitable for the combined CO_2 absorption/regeneration process. Furthermore, the mass transfer enhancement mechanisms of the absorption/regeneration process according to the addition of nanoparticles are presented.

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Nomenclature

E	enhancement ratio	h	hot water
e	experimental error, %	i	inlet
$\dot{m}$	mass flow rate, g/s	l	liquid
$\bar{\dot{m}}$	mean mass flow rate, g/s	NA	nanoabsorbent
T	temperature, °C	o	outlet
U	uncertainty, %	PA	pure absorbent
		R	regenerator
Subscripts		reg	regeneration
A	absorber	s	surface
abs	absorption		
b	bulk		

1. Introduction

1.1. CO_2 removal

CO_2 emissions are increasing because of the increasing use of fossil fuels resulting from industrial development. Thus, global warming and environmental problems are emerging, and alternative energy sources are actively being developed. However alternative energy sources or application technologies still have lower energy density than fossil fuels and are difficult to be commercialized. Hence, they cannot completely replace fossil fuels.

The integrated gasification combined cycle (IGCC), which uses fossil fuels, is a combined power generation system that produces synthetic gas by reacting coal with oxygen and steam under high temperature and pressure, and drives gas and steam turbines using synthetic gas as a fuel. This technology is being spotlighted because it has higher efficiency and is more environment-friendly than the conventional coal thermal power generation. However, synthetic gas contains CO_2, which should be removed and stored using a carbon capture and storage (CCS) technology.

It is difficult to decompose and remove CO_2 because it is a highly stable gas chemically and thermodynamically, having a double bond between carbon and oxygen. The available methods to separate CO_2 gas include absorption, adsorption, membrane, chemical looping and cryogenic methods. CO_2 adsorption by porous materials is an area of active research. Different studies show high selectivity of CO_2 by highly porous activated carbons (ACs) that promise high efficiencies in various fields such as post-combustion CO_2 capture and storage cooling and refrigeration [1,2]. Functionalized adsorption of ACs is still in the small-scale development, and it will take more time to bring this technology to large-scale operations. These methods have their respective advantages and disadvantages; they are used for a suitable purpose or condition because their characteristics are different. Large-capacity systems such as IGCC use the absorption method, which is divided into physical and chemical types according to the capture characteristics of their solvents. The chemical absorption method captures CO_2 from the synthetic gas, mainly using amine-based absorbents, through the chemical bonding of the amine with CO_2. The method generally shows a higher absorption rate than physical absorbents at atmospheric pressure. Therefore, it is suitable for post combustion processes, which are performed at atmospheric pressure. However, removing CO_2 from post-combustion processes has disadvantages including the dilution of CO_2 in nitrogen in flue gases and other pollutants, resulting in parasitic energy costs. In addition, thermal desorption represents a large penalty in the use of amine-based sorbents [3]. Furthermore, amine solutions are highly corrosive and viscous. Recent developments have attempted to overcome the inherent problems of amine aqueous solutions by using solid amine adsorbents, with the additional advantage of low-pressure gas recovery [4,5]. Studies in this area focus on the support characteristics and type of amine. Other types of hybrid materials are being developed using ionic liquids (ILs). Arellano et al. [6] developed a high-capacity hybrid sorbent for CO_2 capture that is based on zinc-functionalized IL impregnated into mesoporous silica beads derived from a calcium-alginate template bead. The results of their study show a dynamic uptake capacity for CO_2 gas as high as 8.7 wt % which is superior to many amine-based systems. These developments will benefit post-combustion CO_2 capture; however, in pre-combustion capture systems, gas–liquid absorption is still the dominant technology.

The physical absorption method makes use of the basic principle of solubility. According to Henry's solubility law, the solubility of a gas increases with decreasing temperature and increasing pressure. These characteristics make the physical absorption method suitable for pre-combustion processes which usually work at high pressures. Furthermore, physical absorbents consume less energy during the regeneration process than chemical absorbents because they only require to be heated close to their boiling point. That is, a physical absorbent requires lower temperature than the chemical absorbent during the absorption process. In a Rectisol process, which uses methanol as the absorbent, the operation temperature should be maintained at approximately −40 °C, which requires a heavy cooling load. The high-energy requirements for the cooling of the absorbents negatively affect the plant efficiency and diminish its ability to reduce carbon.

1.2. Nanotechnology for mass transfer enhancement

The concept of nanofluid was initially introduced by Choi [7]. In addition, the research on nanofluids accelerated by the development of nanofluid-manufacturing technology for the dispersion stability of nanoparticles, which was enabled by the rapid development of nanotechnology and interface engineering. Research in the thermal engineering field is mainly focused on the improvement of thermophysical properties of the refrigerant, which is mainly applied to heat exchangers and refrigeration systems using the heat transfer enhancement effect by nanoparticles. Since 2006, as nanofluids were applied to absorption refrigeration systems for enhancing heat transfer [8], the correlation of mass transfer enhancement by nanoparticles was suggested, gradually increasing research on the enhancement of combined heat and mass transfer by nanofluids. Currently, many studies are being performed by applying nanofluids to the mass transfer field. These include the enhancement of the refrigerant absorption performance in absorption refrigeration systems [9–13], the improvement of the CO_2 absorption performance by adding nanoparticles