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Mass transfer performance of rotating packed beds with blade packings in carbon dioxide absorption into sodium hydroxide solution

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ABSTRACT

This study investigated the mass transfer performance of the rotating packed bed (RPB) with blade packings in carbon dioxide (CO_2) absorption by sodium hydroxide (NaOH) solution. The overall volumetric gas-phase mass transfer coefficients (K_Ga) were compared using 1 vol% CO_2 and 1 mol/L NaOH solution for three RPBs with blade packings with the effects of rotational speed, gas flow rate, and liquid flow rate. As expected, the rotational speed positively affected the K_Ga values for all RPBs. Furthermore, the obtained results indicated that the K_Ga values increased as the inner radius of the bed was increased and the outer radius of the bed was decreased. Moreover, the K_Ga values increased with an increasing liquid flow rate and an increasing gas flow rate for all RPBs. According to the comparison with the RPB with structured packings, the RPB with blade packings had applicability in removing CO_2 from the exhaust gas.

1. Introduction

Vivian et al. [1] examined for the first time the effect of centrifugal force on the desorption of carbon dioxide from water using a packed bed that was attached to a horizontal arm of a centrifuge. This packed bed, which had a height of 0.305 m and a diameter of 0.152 m, was packed with Raschig rings with a size of 0.02 m. The centrifugal acceleration varied from 10 to 63 m/s^2. Experimental results revealed that the volumetric liquid-phase mass transfer coefficient depended on the centrifugal acceleration to the power of 0.41–0.48, suggesting that mass transfer could be enhanced by increasing the centrifugal field. Additionally, consistent with the penetration theory, the liquid-phase mass transfer coefficient varied with the centrifugal acceleration to the power of 1/6. Also, the effective interfacial area increased with the centrifugal acceleration. Accordingly, according to both available experimental data and theoretical analysis, the volumetric liquid-phase mass transfer coefficient could be significantly improved by increasing the centrifugal force.

According to the above discussion, a promising alternative means of increasing mass transfer is to bring liquid into contact with gas in the centrifugal field by rotating the doughnut-shaped packing element. Ramshaw and Mallinson [2] were the first to exploit a centrifugal force as an external force to enhance the efficiency of gas–liquid separation. Accordingly, they developed the rotating packed bed (RPB) for distillation and absorption. This unique technology is referred to as "Higee" (an acronym for high gravity). When the liquid flows through the RPB, it undergoes high acceleration, determined by the rotational speed, reducing the tendency to flood below that in the conventional packed bed. Accordingly, the RPB can be operated at high gas or liquid flow rates. Also, packings with a large specific area and a high voidage can be used. Since the centrifugal acceleration is high, thin films and small droplets can be obtained. The mass transfer would be 10–100 times greater, so the required equipment is physically smaller than that required for the conventional packed bed, so the capital and operating costs are lower [3]. The RPB has been extensively used for distillation [4], VOCs absorption [5–15], CO_2 absorption [16–24], O_3 absorption [25–27], ozonation [28], reactive precipitation [29–32], and stripping [33–35].

Recently, our group was the first to use the RPB with blade packings to absorb volatile organic compounds (VOCs) using water as the absorbent [8], as presented in Fig. 1. According to our previous study, the RPB with blade packings has superior operating characteristics, including a low pressure drop and a high mass transfer [8]. We have presented more results concerning the RPB with blade packings for removing VOCs by absorption with water [8–10,12–15]. In related studies, the VOCs were methanol, ethanol, isopropyl alcohol, 1-butanol, acetone, methyl ethyl ketone, ethyl acetate, and methyl acetate. The RPB with blade packings could effectively process a gas stream that contained VOCs, with a high mass transfer [8–10,12–15].

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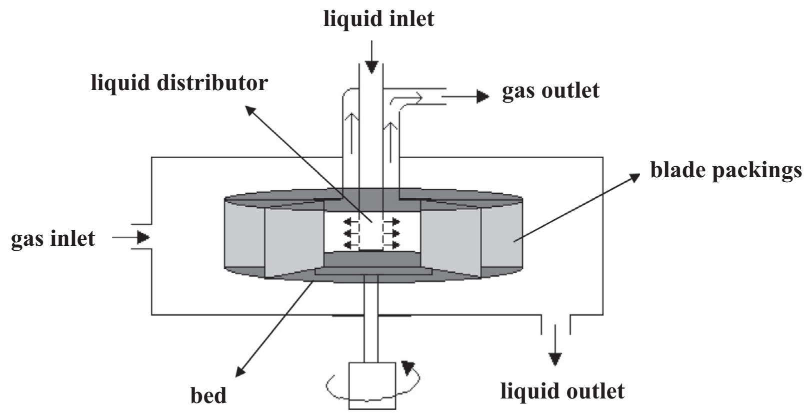

Fig. 1. RPB with blade packings.

To increase applicability of the RPB with blade packings in other absorption processes, investigating the mass transfer performance of the RPB with blade packing is necessary for CO_2 absorption. Moreover, investigating the performance of the RPB with blade packings with various specifications is essential to design the RPB with blade packings accurately and economically. Accordingly, the aim of this study is to examine the mass transfer performance of three RPBs with blade packings in the CO_2 absorption using NaOH solution as the absorbent. Results in this study would provide further insight into the feasibility of CO_2 absorption in the RPB with blade packings.

2. Experimental

Fig. 2 schematically illustrates the experimental setup in this study for CO_2 absorption using the RPB with blade packings by NaOH solution as the absorbent, in which the system was continuously operated under atmospheric pressure. The liquid influent containing NaOH solution was introduced from the influent tank and entered the inner side of the bed from a liquid distributor. Then, the liquid stream traveled radially in the bed due to centrifugal force and, then, exited from the outer side. Finally, the liquid stream splashed onto the stationary housing, and existed at the bottom of the RPB. Simultaneously, the gas stream containing N_2 and CO_2 issuing from the CO_2 cylinder flowed to the RPB. The gas stream flowed inward from the outer side of the bed owing to the pressure drop, left the bed at the inner side, and was then discharged through the top of the RPB. Accordingly, the gas stream and the liquid stream contacted counter-currently within the RPB.

To avoid gas existing from the liquid outlet, the liquid level was maintained in the liquid level tank. Inside the bed, the liquid could be in the forms of thin films over the blade packings as well as small droplets flying within the void owing to a high shear force, resulting in a high gas–liquid interfacial area. The liquid distributor was a tube with one vertical set of holes, having four holes of 0.08 cm diameter. Liquid at a relatively high velocity left from the holes in the liquid distributor and, then, sprayed onto the inner side of the bed. This velocity must be high enough to let liquid

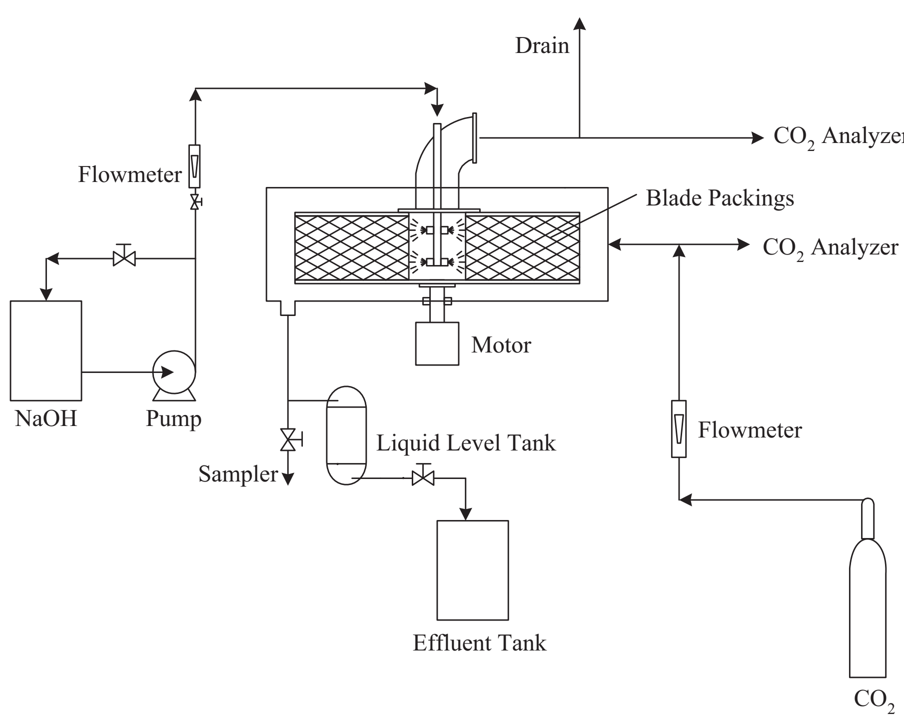

Fig. 2. Experimental setup for CO_2 absorption using NaOH solution.