A relationship of CO$_2$ desorption performance to membrane properties and pressure difference in the membrane flash process with an alumina porous hollow fiber membrane

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Abstract

According to IPCC AR5, the atmospheric concentration of greenhouse gases should be maintained in the range of 430-480 ppm CO$_2$ eq. and global CO$_2$ emission should be near zero at the end of this century in order to achieve the ambitious goal, that is a global temperature rise this century well below 2 °C above the pre-industrial level. Although various kinds of measures to reduce anthropogenic CO$_2$ emission have been proposed and are now being developed, CCS (Carbon dioxide Capture and Storage) is considered to be a crucial measure. In order that CCS is widely implemented, however, it is necessary to develop low-cost and energy-saving separation techniques to recover the CO$_2$ from flue gases from large-scale emission sources such as fossil fuel power plants and steel plants.

Among various CO$_2$ separation techniques, a chemical absorption method using absorbent liquids such as amines is closest to practical use. However, in the chemical absorption method, the conventional solvent regeneration process using steam requires a large amount of heat energy, which results in a large energy penalty. Therefore, the energy consumption in the solvent regeneration process has to be greatly reduced.

Then, we focused on a novel process named a membrane flash process for solvent regeneration. In the membrane flash process, the CO$_2$ rich solvent is fed to the tube side of microporous hollow fiber and it is forced to permeate the membrane by vacuuming the pressure on the shell side. CO$_2$ is expected to be released from the surfaces of tiny droplets of the solvent generated by a steep pressure drop across the membrane and/or in the solvent liquid while it permeates the membrane. The advantages of this process are that high CO$_2$ concentration and smaller energy consumption than the conventional process are realized. However, the CO$_2$ desorption rate strongly depends on the membrane properties such as membrane thickness and pore size as well as the pressure difference between the feed and permeate sides as the driving force of CO$_2$ desorption. In order to minimize the energy consumption, it is necessary to elucidate influence of membrane properties and the pressure difference on the CO$_2$ desorption performance.

Various kinds of alumina porous hollow fiber membrane including two commercial and four hand-made ones were used to investigate the influence of membrane properties. The diameter of the hollow fiber was around 10 mm and the membrane thickness varied from 1.3 to 2.9 mm. The porosity and pore size ranged from 34.5 to 45.9 % and from 0.09 to 0.67 µm, respectively. A piece of each membrane was installed at a center of an acrylic tube of 30 mm in diameter to form an experimental module. The effective length was about 65 mm.

4 M DEA (diethanolamine) aqueous solution was used as the solvent. The CO$_2$ loading of the DEA solution was adjusted to 0.53 mol-CO$_2$/mol-DEA prior to the CO$_2$ desorption experiment. The rich DEA solution was fed into the tube side of the hollow fiber membrane and the pressure on the shell side was vacuumed so that the pressure difference between the tube and shell sides was 45 – 95 kPa. The CO$_2$ desorption experiments were performed at 40 °C, and the flow rate and composition of the
evolved gas were measured to calculate a CO$_2$ desorption rate and a CO$_2$ release ratio. In this study, the CO$_2$ release ratio was defined as a ratio of the released CO$_2$ amount to the releasable CO$_2$ amount contained in the permeating solvent liquid.

The liquid permeation rate through the membrane increased with increasing the pressure difference. The permeance of the membrane was calculated from the relationship of the liquid permeation rate to the pressure difference for each membrane. Also, the results showed that the CO$_2$ release ratio had a close relationship with the contact time while the solvent passing through the membrane. The contact time was determined by the pressure difference $\Delta P$ and the membrane properties. In this study, the membrane properties were represented by the membrane permeance $B$. Moreover, CO$_2$ desorption is driven by the difference in CO$_2$ concentration between the liquid and gas phases. Then, the CO$_2$ concentration difference was expressed as the degree of supersaturation $S$ which was defined as the difference between the CO$_2$ loading of the supplied rich solvent and the CO$_2$ loading equilibrated with the CO$_2$ partial pressure on the shell side in this study. As a result, it was found out that there was a good correlation between the CO$_2$ release ratio $\beta$ and the term of $\Delta PBS$, and the correlation was expresses by the following equation:

$$ \beta = 16(\Delta PBS)^{-0.55} \quad (R^2 = 0.93) $$

Thus, this study indicated that the CO$_2$ desorption performance in the membrane flash process could be predicted from the membrane properties and the pressure difference as the operating condition.