Possibility of drastically enhancing the capture capability of CO2 with ammonia through the control of droplet size distribution

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In spray towers absorbing gases using liquid absorbent, capture performance is usually predicted by primary variables such as gas and sorbent flow rates, tower size and mean drop size, but capture performance is also affected by secondary conditions which are related to non-uniformities: in gas distribution, liquid distribution, drop-size distribution and loss of droplets to the wall. Secondary factors all aggravate the performance, and drop-size non-uniformity is the most important factor.

In chemical absorption of CO2, energy required for regeneration has to be reduced by a factor of 2-3 than the current level for economical operation. Since the energy for regeneration is directly proportional to the total liquid flow rate, absorption with a smaller amount of absorbent liquid per captures CO2, called the capture capacity, is required to reduce the energy cost.

In all the contemporary spray towers using simple spray nozzles, capture performance is rather poor, with the maximum capture capacity or final saturation of the sorbent stays at about 10% level at high capture efficiency conditions. And this study aims to check the possibility of enhancing the capture capacity by narrowing the size distribution of sprayed droplets.

Method of capture performance analysis

Model system for analysis was a 1-D spray tower where all the non-uniformities were eliminated except the drop-size non-uniformity. Gas and liquid flows were uniform in the reactor space, and poly-disperse drop size distribution was modelled by a log-normal distribution defined by count-median diameter (d_{CMD}) and geometric standard deviation (σ). Reactor tower was divided into a number of 1-D cells, and mass balance equations for each cell were numerically solved using MATLAB.

Reference conditions used for analysis were for lab-scale spray and packed towers of Qing *et al.* (2011), as summarized in Table 1. Absorbent flow (Q_l) and droplet size deviation (σ) were varied.

Table 1. Reference condition for performance prediction.

Variables	values
Gas velocity	0.05 m/s
CO2 concentration	15 %
NH3 concentration	8 %
Henry constant	0.8877
Reaction rate constant	304 m³/mol/s
Mean drop size (d_{CMD})	180 μm

Local mass transfer coefficient used for analysis was borrowed from Choi et al. (2016), which is the first ever formula for chemical absorption of CO2 with ammonia and is in a proper form for Eulerian analysis.

$$m_g'' = \frac{\dot{m}_{CO_2}}{A} = k^{0.48} \cdot C_{g,s} \cdot C_l \left[\frac{2.15E-6}{C_{l,i}^{0.5}} + \frac{1.40E-7}{d^{0.3}} \left(1 - \frac{C_l}{C_{l,i}} \right)^{2.5} \right]$$

Results and discussion

Tower length required for capture efficiency η = 90% (L_{90}) at a fixed absorbent flow or absorbent flow (Q_l) for η = 90% in a given tower length was calculated and compared among various drop-size deviation (σ).

It is clear from Fig. 1 that both L_{90} and Q_l was reduced by a factor 3 and 4 as σ reduced from 2.0 to 1.6 and 1.2, respectively. It is also shown that the experimental spray tower (pink symbol) corresponds to a 1-D tower with σ = 2.5, for which the enhancement factor is about 10.

It is thus expected that the same high η is possible with much smaller tower length or absorbent flow, if only drop-size distribution is made narrower. Same results were obtained for a 15-times larger system, too.

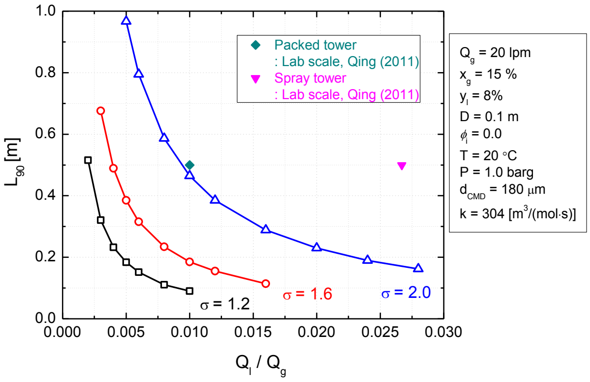

Figure 1. Tower length required for η = 90% (L_{90}) at various absorbent flow (Q_l) and drop-size deviation (σ).

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