Mass Transfer coefficients - Experimental Evaluation of CO2 Capture with Structure Packing

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### Antecedents

- Amine absorption technology is considered to be viable for low pressure flue gas CO\(_2\) capture because of MEA-CO\(_2\) fast reaction rate.

- The Kyoto protocol is an essential step to mitigate the emission of pollutants and the CCS technologies are the instruments of CO\(_2\) capture and sequestration.

- MEA absorption processes are associated with high capital and operating cost because of amount of energy is required for solvent regeneration and severe operating problems are present such as corrosion and solvent loss and degradation.

- The difference between categories for capturing CO\(_2\) from power plants is depended on fuel treatment, its oxidation, CO\(_2\) concentration, and gas pressure.
Objectives

- The objective of this work is to study CO$_2$ absorption by experimental absorption column, using metal structured packing material named ININ18. This material was developed by Mexican National Institute of Nuclear Research (ININ by its acronym in Spanish). This material was compared with commercial structured packing.

- The present study provides comprehensive performance of structured parking in CO$_2$ absorption application.
The general method involves contacting a gas stream to an aqueous amine solution which reacts with the CO$_2$ by acid-base neutralization reaction to form a soluble carbonate salt. This reaction is reversible, allowing the CO$_2$ gas to be liberated by heating in a separate stripping column. The elementary steps for the reaction are represented by the following equilibrium reactions:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2\text{O}$</td>
<td>$\text{H}_3\text{O}^+ + \text{OH}^-$</td>
</tr>
<tr>
<td>$\text{CO}_2 + 2\text{H}_2\text{O}$</td>
<td>$\text{H}_3\text{O}^+ + \text{HCO}_3^-$</td>
</tr>
<tr>
<td>$\text{HCO}_3^- + \text{H}_2\text{O}$</td>
<td>$\text{H}_3\text{O}^+ + \text{CO}_3^{2-}$</td>
</tr>
<tr>
<td>$\text{MEAH}^+ + \text{H}_2\text{O}$</td>
<td>$\text{H}_3\text{O}^+ + \text{MEA}$</td>
</tr>
<tr>
<td>$\text{MEACOO}^- + \text{H}_2\text{O}$</td>
<td>$\text{HCO}_3^- + \text{MEA}$</td>
</tr>
</tbody>
</table>
Methodology

The methodology was divided into three parts:

- The use of different packings to compare ININ18 material behavior.
- The use of hydrodynamic and mass transfer models.
- Gas chromatograph equipment used was Varian 3760 with two detectors: flame ionization and thermal conductivity and three chromatographic columns used on the type of combustion gases: \( \text{CH}_4, \text{C}_6\text{H}_{14}, \text{CO}_2 \) and \( \text{CO} \). The chromatographs were provided by HP-5MS column of 30 meters long with a diameter of 0.25µm, temperature was carried at 35°C and 5 minutes of routine. The concentrations were determined by comparing with standard area from standard known composition.
On the bases of conventional definitions of mass transfer units, the height of a gas phase transfer unit and the height of a liquid phase transfer unit respectively are:

\[ H_G = \text{HTU}_G = \frac{U_G}{K_G \alpha e \rho_G} \]
\[ NTU = \frac{y_1 - y_2}{(y-y^*)_M} \]

\[ H_L = \text{HTU}_L = \frac{U_L}{K_L \alpha e \rho_L} \]
\[ Z = \text{HETP}^* \cdot NTU \]

\[
\frac{\Delta P}{\rho g Z} = \frac{\Delta P}{\rho g Z} \chi Ax B
\]

\[
A = \left\{1 - \varepsilon \left[1 - \frac{k}{\varepsilon} \left[1 + 20 \left(\frac{\Delta P}{\rho g Z}\right)\right]\right]\right\}^{-1}
\]

\[
B = \left[1 - \frac{k}{\varepsilon} \left[1 + 20 \left(\frac{\Delta P}{\rho g Z}\right)\right]\right]^{10}
\]

\[
\left(\frac{K_a s}{D_a}\right) = 0.054 \left[\frac{(U_{\text{eff}} + U_{o,\text{eff}})}{\mu_a} s^3 \left(\frac{\mu_a}{D_a \rho_a}\right)\right]^{0.3}
\]

\[
K_z = \sqrt{\frac{D_z U_{z,\text{eff}}}{\pi s C_e}}
\]

\[
a = \frac{F}{\rho g} \left[\frac{29.12 \left(We_z Fr_z\right)^{0.15} s^{0.359}}{Re_z ^{0.2} \varepsilon^{0.6} \left(1 - \cos \gamma\right) \left(Sen \theta\right)^{0.3}}\right]
\]
The system studied was MEA at 30 weight percentage in aqueous solution countercurrent with CO₂ flue gas. The process was carried out in an absorption column with dimensions of 4.0 meters of height and 0.3 meters of diameter.
Characteristic of ININ18 structure packing material as liquid-gas contact device and others materials of Sulzer Ltd.

<table>
<thead>
<tr>
<th>Type</th>
<th>Stainless steel</th>
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<tbody>
<tr>
<td>Wire gauge</td>
<td>18</td>
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<tr>
<td>Porosity ($\varepsilon$)</td>
<td>0.9633</td>
</tr>
<tr>
<td>Geometric area $a_p$</td>
<td>418 m²/m³</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.252 m</td>
</tr>
<tr>
<td>Height</td>
<td>0.19 m</td>
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<tr>
<td>Corrugated angle</td>
<td>45º</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Packing</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$\theta$ (°)</th>
<th>$a_p$ (m²/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulzer BX</td>
<td>15</td>
<td>2</td>
<td>0.35</td>
<td>60</td>
<td>450</td>
</tr>
<tr>
<td>ININ 18</td>
<td>2.4024</td>
<td>0.3351</td>
<td>1.071</td>
<td>45</td>
<td>418</td>
</tr>
<tr>
<td>Mellapak 250Y</td>
<td>5</td>
<td>3</td>
<td>0.45</td>
<td>45</td>
<td>250</td>
</tr>
</tbody>
</table>
Mass transfer results

<table>
<thead>
<tr>
<th></th>
<th>HTUoG</th>
<th>m</th>
<th>0.317</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTUoL</td>
<td>m</td>
<td>0.0273</td>
<td></td>
</tr>
<tr>
<td>KGae</td>
<td>s⁻¹</td>
<td>3.76</td>
<td></td>
</tr>
<tr>
<td>KGae</td>
<td>s⁻¹</td>
<td>0.2978</td>
<td></td>
</tr>
</tbody>
</table>

Measurement of CO₂ absorption percentage versus time
ININ18 structured packing material as liquid gas contactor

Pressure drop versus gas velocity

Liquid holdup versus F-factor

Height of mass transfer unit in gas phase

Height of mass transfer unit in liquid phase
ΔP/Z data versus gas flow to Sulzer BX, ININ18 and Mellapak 250Y

Kg data versus gas flow to Sulzer BX, ININ18 and Mellapak 250Y

HTUOG data versus gas flow, Sulzer BX, ININ18 and Mellapak 250Y
Conclusions

The use of Sulzer BX and ININ18 packings are recommended in order to capture CO2. Both were the most efficient in the mass transfer because they present the lowest values of the column height and the biggest KGae values, respectively, even though ININ18 packing was the biggest value of irrigated pressure drop of the studied structured packing types.

This was the consequence of their geometric characteristics: bigger porosity and bigger geometric area than Sulzer BX and Mellapak types.

The results of CO2 capture system were found to be relatively accurate and reproducible. The increase in kGae value indicates the speed increase in which the solute is transferred into the liquid phase, the highest value of kGae in the region is loaded with a range of 80 to 90% compared to the flooding regimen.

In this work was evaluated experimental CO2 removal with MEA absorption from CO2-air flue gas by using a set of equipment specifications and operating conditions.
Acknowledgments

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Thank you for your attention!