Upscaling of the enzyme enhanced CO$_2$ capture process

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Introduction

More than 80% of the world's energy is generated from fossil fuels today. The fossil fuel consumption for energy generation is expected to rise in the coming decades [1]. The emission of greenhouse gases will continue unless advanced gas cleaning technologies are applied to the exhaust gases from fossil fuel fired power plants.

Theory

The enzyme Carbonic Anhydrase (CA) can catalyze the reaction rate with CO$_2$ in slow absorbing bicarbonate forming solvents

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \]

This will overcome the kinetic limitation of these solvents, while maintaining the beneficial properties for desorption.

The enzyme kinetics for reversible enzyme reactions need to be reversed (>50% of total process energy required here).

Mass transfer model

Mechanistic model for reversible enzyme kinetics

\[ \frac{k_{\text{liq}}}{2} \cdot \frac{S}{E-S} \cdot E \cdot P \cdot HCN \]

Implemented into mass transfer model

\[ \frac{L}{G} \cdot \frac{C_{\text{exp}} - HCO_3^-}{C_{\text{exp}}} \]

Temperature dependence

Solvent concentration

CO$_2$ partial pressure

Sensitivity analysis

Influence of different process parameters on CO$_2$ capture efficiency.

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Carbon capture and storage technology (CCS)

Clean gas

Absorber

Flue gas

Absorption of CO$_2$ from flue gas into liquid solvent; chemical reaction enhances mass transfer significantly.

Desorption of pure CO$_2$ and regeneration of solvent; reactions need to be reversed (>50% of total process energy required here).

Ideal solvent for CCS processes

- High reaction rates / mass transfer
  - Smaller equipment size
  - Less capital costs
- Low heat of absorption
  - Lower energy requirement
  - Lower operational costs

Reaction speed ~ heat of absorption [2]

- Fast reacting solvents have high energy requirement
- Energetically favorable solvents need high capital costs

Reaction model

Accurate prediction of the experimental pilot plant experiments with CAPCO2 model and implemented enzyme kinetic model for CA of:

- CO$_2$ capture efficiency at different column heights
- CO$_2$ capture efficiency (%)
- CO$_2$ capture efficiency at different liquid to gas ratios

Mass transfer model validation

- Solvent loading inside the absorber column
- CO$_2$ capture efficiency (%)
- CO$_2$ capture efficiency at different liquid to gas ratios

Conclusions

- The enzyme enhanced CO$_2$ capture process can be simulated with a mechanistic enzyme kinetic model in pilot scale
- The model can accurately predict the influence of enzyme concentration, L/G ratio and column height on the CO$_2$ capture efficiency.
- CO$_2$ capture efficiency is very sensitive to enzyme concentration and L/G ratio.
- The presented model provides a solid basis for enzyme enhanced CO$_2$ capture simulation.

References:

Abbreviations:
MDEA: N-methyldietanolamine

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