Upscaling of enzyme enhanced CO2 capture - DTU Orbit (24/12/2018)

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Fossil fuels are the backbone of the energy generation in the coming decades for USA, China, India and Europe, hence high greenhouse gas emissions are expected in future. Carbon capture and storage technology (CCS) is the only technology that can mitigate greenhouse gas emissions from fossil fuel fired power by selectively capturing CO2 from flue gases. High capital and high operational costs of this process are the major obstacles of industrial implementation. In the field of CCS the chemical absorption process is the most mature technology. The use of kinetic rate promoters that enhance the mass transfer of CO2 with slow-capturing but energetically favorable solvents can open up a variety of new process options for this technology.

The ubiquitous enzyme carbonic anhydrase (CA), which enhances the mass transfer of CO2 in the lungs by catalyzing the reversible hydration of CO2, is one very promising mass transfer rate promoter for CCS. This process has been previously been tested successfully in lab scale and in some rare cases in pilot scale, but no validated process model for this technology has been published yet.

This PhD thesis presents an investigation of the feasibility of enzyme enhanced CO2 capture technology by identifying the potentials and limitations in lab and in pilot scale and benchmarking the process against proven technologies. The main goal was to derive a realistic process model for technical size absorbers with a wide range of validity incorporating a mechanistic enzyme kinetic model and validating it against in-house pilot plant experiments.

The work consisted of identifying a suitable enzyme-solvent system and the ideal process conditions by comparing mass transfer rates of different solvents and enzyme enhanced solvents in a lab scale wetted wall column. A kinetic model for the mechanistic enzyme reactions was developed for MDEA (Nmethyl-diethanolamine) solutions capable of describing the mass transfer of CO2 for absorption and desorption. It incorporates the influence of all relevant process conditions for technical absorbers, such as: temperature, solvent concentration, enzyme concentration, CO2 concentration in the gas and liquid phase, as well as bicarbonate concentration in the liquid phase.

The process with enzyme enhanced MDEA was scaled up, and absorption experiments were carried out on a 10 m high pilot absorber column. The influence of enzyme concentration, column height, as well as solvent flow rates were determined for 30 wt% MDEA in over 50 runs and compared to over 30 pilot plant runs with the industrial standard solvent 30 wt% MEA (monoethanolamine) under the same process conditions. The mass transfer performance of enzyme enhanced solutions was found to be close to the industrial standard.

The pilot plant experiments could be accurately predicted with the in-house absorber column model CAPCO2 after the kinetic enzyme model from the lab experiments was implemented. The model can very accurately simulate the influence of each process parameter tested.

For targeting the thermal stability of the enzyme in desorption, an alternative low temperature process without reboiler was presented. A stripping gas carrier is utilized in this process to avoid thermal deactivation of the enzymes in the solvent regeneration; its technical feasibility was successfully tested in pilot scale desorption experiments. The experiments at lab and pilot scale have clearly proven CA’s potential in CCS. The presented validated absorber column model together with the low temperature regeneration process can be used to simulate and optimize the enzyme enhanced CO2 capture process and benchmark this novel technology against conventional processes.

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