GCEP

Global Climate & Energy Project

STANFORD UNIVERSITY

Carbon-based Sorbents for Selective CO_2 Capture

Investigators

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Objective

The objective of this project is to develop affordable, regenerable carbon-based materials that can selectively capture carbon dioxide (CO_2) emitted from power plants. Researchers will use sorbent-based technologies that mimic the biological process of carbon capture in mammalian blood, with the goal of enhancing the mass transfer of CO_2 from the gas phase to the adsorbed phase and improving the kinetics associated with adsorption and desorption (regeneration) processes.

Background

Sorbent technologies for CO_2 capture have several potential advantages over conventional amine-based solvent absorption approaches. The primary energetic expense associated with solvent-based CO_2 capture is heating the water present in the amine solvent. Plant parasitic energy load can be decreased since water is absent in an adsorption-based approach, thereby reducing the energy requirements associated with CO_2 regeneration. Other benefits of sorbents are the flexibility associated with the choice in pore size. Mesoporous carbon-based materials (which have pores from 2 to 50 nanometers in diameter) will allow heat to readily dissipate during the adsorption process and easily transfer into the system for regeneration, thus minimizing energy use and capture/regeneration cycle time.

Despite these advantages, current sorbent technology is limited, because the most promising sorbents [e.g., metal-organic frameworks (MOFs) and zeolites] are not selective to CO_2 over water vapor. To address this limitation, the researchers have turned to nature by focusing on carbonic anhydrases – natural enzymes found in the red blood cells of mammals that require the presence of water to be effective. In mammals, carbonic anhydrases capture CO_2 as bicarbonate, which dissolves in the blood and transports oxygen to the lungs. The kinetics of bicarbonate formation via carbonic anhydrase are about six orders of magnitude faster than CO_2 binding via an amine-based solvent, the most advanced process for carbon capture used by industry today.

Approach

Using carbonic anhydrases for CO_2 capture has only been attempted in solution. Using it for sorbent technology will significantly reduce the energy needed for regeneration. Additionally, this will be one of the first studies that investigates sorbent performance in realistic flue gas environments, including water vapor, CO_2 and typical hazardous air pollutants (HAPs) such as SO_2, NO and NO_2. Researchers will develop desirable characteristics of the sorbent and the mesoporous carbon structure (MCS) using engineering and computational models, synthesis and characterization techniques.

Sorbents: An important aspect of the carbonic anhydrase sorbent work will involve effective tuning of the pore structure and surface chemistry to minimize diffusion limitations. A combination of chemical and physical adsorption mechanisms will likely be responsible for CO_2 capture in the sorbents tested. These mechanisms will provide low energy of regeneration, while ensuring adequate mass transfer from the gas to adsorbed phase. X-ray diffraction studies will characterize the crystallinity of the carbon supports, whose surface will then be used to immobilize functional molecules

Mesoporous carbon structure: Carbon-based materials, which are affordable and Earth-abundant, will be used as the sorbent structure, providing a scalable surface chemistry to optimize the mass transfer of CO_2. One common approach for preparing the MCS is to use ordered mesoporous silica as a hard template, fill it with a carbon source material, and then remove the material from the template by applying heat. A modified version of this method will be applied using co-polymers and additional carbon sources to form both the template and the ordered carbon structure, thus eliminating the need to fill an inorganic template with a carbon source. The ideal target structure illustrated in Figure 1 will have a uniform pore size to minimize diffusion limitations and the pressure drop throughout the sorbent.

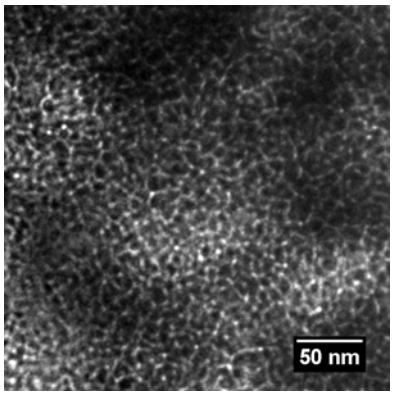

Figure 1: Transmission electron microscopic image of the pore structure of a cylindrical mesoporous carbon material.

Once the sorbent and MCS structure are developed, they must be integrated via novel chemical coupling. Functional models of carbonic anhydrases (discrete monomer zinc hydroxide complexes) will be attached to the support structure through a two-step covalent attachment strategy. Experiments in a simulated combustion flue gas environment will measure the adsorption kinetics of the completed carbon capture structure. Figure 2 shows the experimental set-up.

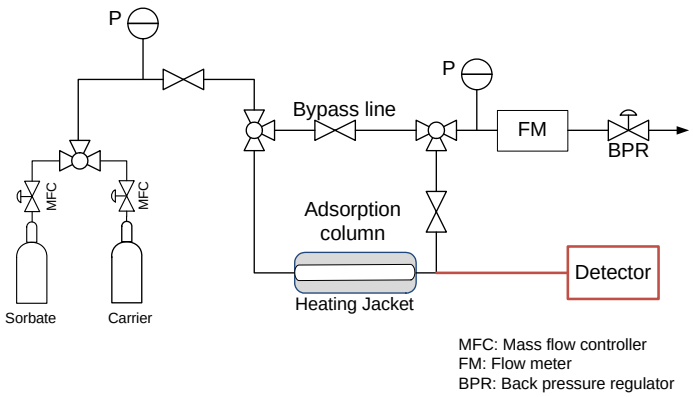

Figure 2: Experimental apparatus for the combustion flue gas experiments.