PROJECT facts

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

Sequestration

03/2006

CO_2 Selective Ceramic Membrane for Water-Gas-Shift Reaction with Simultaneous Recovery of CO_2

Background

The water-gas-shift (WGS) reaction, $CO + H_2O \leftrightarrow H_2 + CO_2$, is used to increase the hydrogen content of synthesis gas. However, this reaction is equilibrium limited. One approach for overcoming this limitation is to carry out the reaction in a reactor with walls that are CO_2 permeable. This continuously removes CO_2 from the system and allows the reaction to continue.

This project involves the development of a technique for depositing hydrotalcite onto a ceramic membrane suitable for implementing the reactive separation concept with the WGS reaction in integrated gasification combined cycle (IGCC) systems. The membranes are being developed using available sol gel and chemical vapor deposition (CVD) preparation techniques. The hydrotalcite is permeable to CO_2 but plugs the pores, preventing passage of other gases. The hydrothermal and chemical stability in a simulated WGS reaction environment will be evaluated to confirm the inert material properties of the ceramic membrane. Then, a membrane reactor (MR) study will be conducted to demonstrate the benefit offered by this membrane. Finally, process feasibility will be demonstrated in a test module, and an economic evaluation will be performed to estimate the positive effect of using a WGS-MR in IGCC coalfired power plants.

Primary Project Goal

The primary objective of this program is to develop a defect-free hydrotalcite membrane for selective CO_2 removal that will be effective in the water-gas-shift reaction environment, i.e., 300 to 600°C and in the presence of steam.

Objectives

- Conduct a screening study to select an optimal material for developing a membrane and determine the optimum operating conditions in terms of temperature and steam content of the gas for selective CO_2 removal (good thermal, hydrothermal and chemical stability).
- Fabrication of the desired membrane in tubular geometry and verification of the feasibility of CO_2 separation along with the conversion enhancement.

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COST

Total Project Value
$900,000

DOE/Non-DOE Share
$720,000 / $180,000

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Accomplishments

Hydrotalcite was investigated as both an adsorbent and a membrane for CO_2 separation. The adsorption isotherm and intraparticle diffusivity for the hydrotalcite-based adsorbent were experimentally determined, and found to be suitable for low temperature shift (LTS) of the WGS reaction. The hydrotalcite-based membranes were synthesized using Media and Process Technonlogy's (MPT) commercial ceramic membranes as substrate. These experimental membranes were characterized comprehensively in terms of their morphology, and CO_2 permeance and selectivity to demonstrate the technical feasibility. In parallel, an alternative CO_2 affinity membrane (carbonaceous base) developed by MPT was characterized and also demonstrated enhanced CO_2 selectivity at the LTS-WGS condition. Each of these membranes requires additional optimization to reduce defects.

Based upon the unique CO_2 affinity of the hydrotalcite at the LTS/WGS environment, an innovative membrane reactor, Hybrid Adsorption and Membrane Reactor (HAMR) was developed. The HAMR combines the reaction and membrane separation steps with adsorption on the membrane feed or permeate side. A mathematical model was developed to simulate this one-step process. Finally, a bench-top reactor was employed to generate experimental data, which were consistent with the prediction from the HAMR mathematical model. Preliminary results indicate HAMR offers potential to achieve near 100% CO conversion, and produce both a high purity hydrogen product and a concentrated CO_2 stream.

Benefits

This combined shift reaction and CO_2 separation system project will produce a hydrogen rich gas which is at high pressure, high temperature and contains significant quantities of steam making it highly suitable for direct firing in a gas turbine with high efficiency. The use of an improved WGS-MR with CO_2 recovery capability is ideally suited to integration into the IGCC power generation system. Thus, the hydrogen (high pressure and CO_2-free) produced from the IGCC can be used either as a product for power generation via a turbine or a fuel cell, or as a reactant for fuels and chemicals production.