the ENERGY lab

PROJECT FACTS

Carbon Capture

Research and Education of CO_2 Separation from Coal Combustion Flue Gases with Regenerable Magnesium Solutions

Background

Fundamental and applied research on carbon capture and storage (CCS) technologies is necessary to allow the current fleet of coal-fired power plants to comply with existing and emerging environmental regulations. These technologies offer great potential for mitigating carbon dioxide (CO_2) emissions into the atmosphere without adversely influencing energy use or hindering economic growth.

Deploying these technologies in commercial-scale applications requires a significantly expanded workforce trained in various CCS technical and non-technical disciplines that are currently underrepresented in the United States. Education and training activities are needed to develop a future generation of geologists, scientists, and engineers who possess the skills required for implementing and deploying CCS technologies.

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL), through funding provided by the American Recovery and Reinvestment Act (ARRA) of 2009, manages 43 projects that received more than $12.7 million in funding. The focus of these projects has been to conduct carbon capture and geologic storage training and support fundamental research projects for graduate and undergraduate students throughout the United States.

Project Description

DOE is partnering with the University of Cincinnati to conduct research and training in the post-combustion separation of CO_2 from coal-fired power plant flue gas using regenerable magnesium hydroxide [$Mg(OH)_2$] slurry solutions. Magnesium hydroxide is readily available commercially and may be easily and economically reclaimed from power plants using lime-based flue gas desulfurization (FGD) systems. The research focus is to effectively and reliably separate CO_2 from flue gas for potential storage or utilization purposes by using $Mg(OH)_2$ slurry solutions to achieve 95 percent CO_2 purity. Research will also be conducted on the regeneration of the rich $Mg(OH)_2$ solution in a CO_2 desorber. Carbon dioxide absorption is anticipated to take place at 52 °C after SO_2 removal in a wet FGD system, followed by a regeneration step. A schematic of the proposed CO_2 separation system is shown in Figure 1.

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PARTNERS

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PROJECT DURATION

Start Date	End Date
12/01/2009	09/31/2013

COST

Total Project Value
$389,114

DOE/Non-DOE Share
$299,851 / $89,263

Government funding for this project is provided in whole or in part through the American Recovery and Reinvestment Act.

PROJECT NUMBER

FE0001834

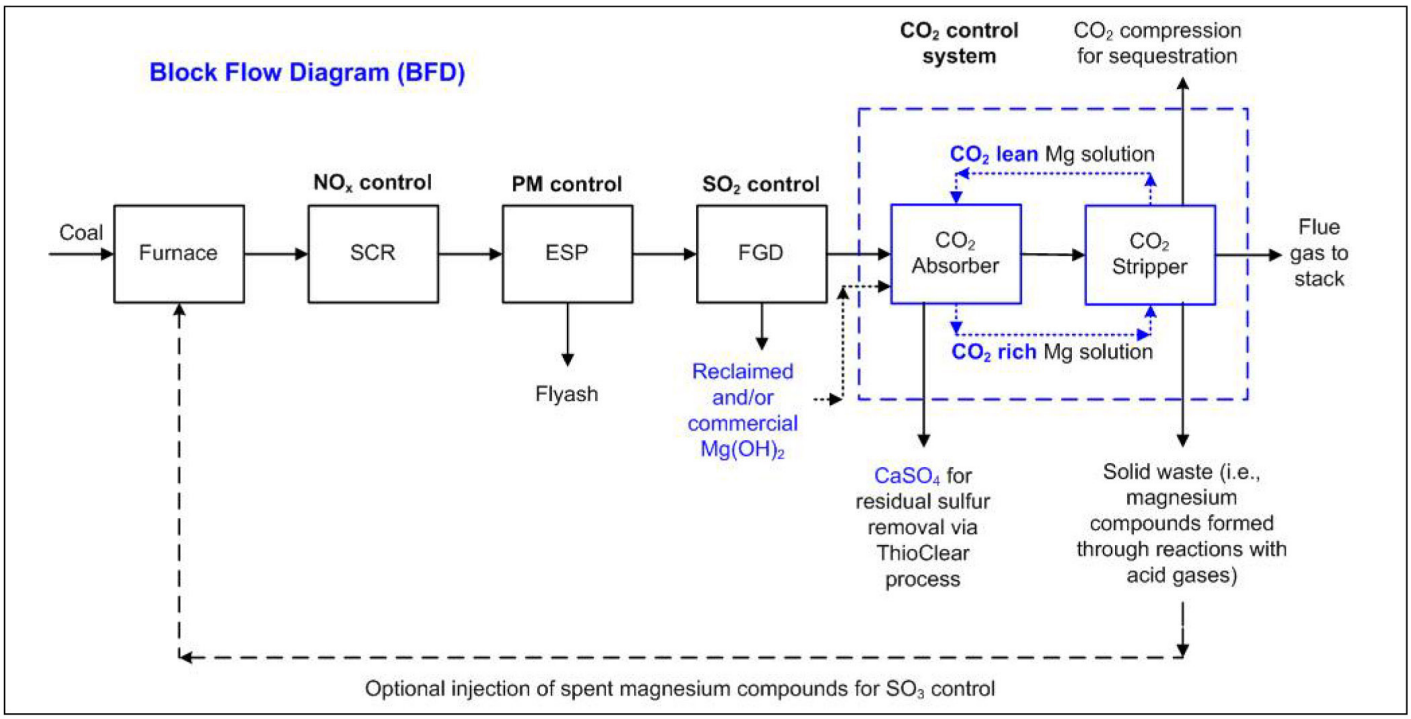

Figure 1. Block flow diagram of the University of Cincinnati's concept of post-combustion separation of CO_2 from coal-fired flue gas using regenerable $Mg(OH)_2$ solutions.

Project personnel will conduct laboratory research to obtain fundamental experimental data including the optimal liquid-to-gas ratio for fluid flow rates; dissolution rate of $Mg(OH)_2$; impact of acid gases entering the absorber; optimum $Mg(OH)_2$ composition; mass transfer and reaction between gas, liquid, and solid phases; and the kinetics of magnesium carbonate ($MgCO_3$) formation. This research data will be used to develop a model to obtain design information for a pilot-scale unit and evaluate the economics of the CO_2 separation system. The project incorporates engineering education for chemical and environmental engineering students in an effort to provide a trained workforce necessary for implementing and deploying CCS technologies on a commercial scale.

Goals/Objectives

The goal of this project is to integrate ongoing research on regenerable magnesium solutions for CO_2 separation from coal-fired flue gas with engineering education in the field of CCS. Regenerable magnesium solutions have the potential to contribute to CO_2 capture while minimizing the overall cost of capture. The research objective is to determine the proof of concept of the $Mg(OH)_2$ slurry technology by conducting additional investigations with the assistance of chemical and environmental engineering graduate students.

Accomplishments

- As of September 2012, seven students had accumulated 4,639 training-related hours under the program.

- A small pilot-scale CO_2 absorption system comprising a furnace, heat exchanger, and CO_2 turbulent contact absorber was completed and optimized for 90 percent CO_2 removal efficiency. Bubble and packed absorber columns were tested in the pilot-scale system for CO_2 removal using NaOH and $Mg(OH)_2$ solutions.

- A kinetic study of $MgCO_3$ formation was conducted. Batch experiments were completed for $MgCO_3$ formation at three different temperatures (20, 52, and 65 ˚C) both with pH control (at 8.6) and without pH control by using sodium bicarbonate as a source of dissolved carbon. The results show that up to 10 weight percent of absorbed carbon can end up in a form of $MgCO_3$ in a magnesium solution at 52 ˚C within 1 minute.

- A vapor-liquid-solid equilibrium (VLSE) study for CO_2 regeneration was performed for the $Mg(OH)_2$-CO_2-H_2O system in a high-pressure vessel to provide basic information on the operating conditions to be used for the CO_2 desorber.

- The characteristics of $Mg(OH)_2$ and $MgCO_3$ slurries were studied to identify the mean particle size of industrial and reagent-grade powders. Scanning electron microscope and x-ray diffraction data show that magnesium carbonate was formed during the absorption process.

- A VLSE study for a 0.1 molar (M) $Mg(OH)_2$-CO_2 system was conducted under total system pressure of 1 atmosphere. The equilibrium distribution of magnesium and carbon species was calculated under various pH conditions using PRO/II process engineering software.

- Multiple CO_2 absorption-desorption cycles were conducted to improve capture performance with various additives and under different operating conditions.

- A mathematical model using a two-film theory for CO_2 gas absorption in a bubble column system was developed. The model was validated with experimental results for CO_2 absorption in deionized water and predicted the experimental results with good accuracy.

- A $Mg(OH)_2$ dissolution study was conducted to determine the rate at which the $Mg(OH)_2$ dissolves from the solid slurry and becomes available for the reaction with absorbed CO_2. Dissolution rates were obtained for various temperatures and particle sizes. The impact of pH, temperature, agitation speed, and $Mg(OH)_2$ concentration on the dissolution rate was studied. A manuscript for a peer-reviewed journal publication was written and submitted.

- A dissolution flux model was developed based on the dissolution study results. The model results were found to be in good agreement with experimental results.

- Steady-state operation of CO_2 absorption achieving greater than 90 percent CO_2 removal was accomplished in a laboratory-scale bubble column system at 52 °C. This was based on an overall mass-transfer coefficient determined from mathematical modeling.

Benefits

The project is making a vital contribution to the scientific, technical, and institutional knowledge necessary to establish frameworks for the development of commercial-scale CCS. Results from this research are helping to advance the CO_2 solvent research goals of increasing loading capacity while reducing the energy demand and capital costs of carbon capture. This project is supporting several graduate students over the project period in an effort to provide a trained CCS workforce.