Development of a Novel Gas Pressurized Stripping-Based Technology for CO_2 Capture from Post-Combustion Flue Gases

primary project goals

Carbon Capture Scientific has performed bench-scale development, testing, and computer simulations of a novel solvent-based carbon dioxide (CO_2) capture technology, known as gas-pressurized stripping (GPS) process. The GPS technology has the potential to significantly reduce the energy penalty associated with solvent regeneration and compression by operating the regeneration step at higher pressures, which in-turn reduces the compression requirements for CO_2 storage.

technical goals

- Computer simulation to predict GPS column performance under different operating conditions.
- Lab-scale tests of individual process units to document experimental results and obtain necessary information to progress the technology to the next level.
- Experimental investigation of selected solvents to minimize the economic risk of the proposed technology.
- Design, build, and operate a bench-scale GPS unit capable of processing about 500 standard liters of actual coal-derived flue gas per minute (SLPM) at the National Carbon Capture Center (NCCC).
- Derive a techno-economic analysis (TEA) of the GPS process on a pulverized coal plant compared to a baseline pulverized coal plant.

technical content

The project conducted lab-scale individual process unit tests and integrated continuous bench-scale GPS system tests using actual coal-derived flue gas at the NCCC. The overall objective was to reduce the energy consumption and capital cost of the CO_2 capture process.

Computer simulation tasks investigated the GPS column behavior under different operating conditions, optimizing the column design and operating conditions, leading to a capital cost increase less than five percent over the baseline monoethanolamine (MEA) case. Solvent related tasks collected information on the solvent operating cost when a modified, commercially-available solvent is used in the GPS process. Experiment related tasks with the major individual units obtained information needed for the bench-scale unit design, and the integrated continuous bench-scale GPS system tests using actual coal-derived flue gas at the NCCC provided all the necessary information for the next level pilot-scale process and engineering design along with the GPS system performance data. Testing at the NCCC demonstrated that the GPS process can

technology maturity:
Bench-Scale, Real Flue Gas

project focus:
Gas-Pressurized Stripping

participant:
Carbon Capture Scientific

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predecessor projects:
N/A

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100%

achieve 90 percent CO_2 removal from typical coal-derived flue gas. The GPS process can produce high-pressure CO_2 product with required purity. Finally, the GPS process has an energy consumption much lower than that of the DOE MEA baseline case. A TEA of the GPS process was derived, showing that a GPS-based pulverized coal (PC) plant has net power production of 647 MW, greater than the MEA baseline study. This increase is attributed to the lower steam requirement and smaller CO_2 compression auxiliary power consumption. The TEA also found that the 20-year levelized cost of electricity for a supercritical PC plant with GPS-based PCC is 52 percent more than the baseline supercritical PC plant without CO_2 capture but 23 percent lower than the baseline supercritical PC plant with MEA. Figure 1 is a flowchart for the GPS process. Figure 2 shows the GPS-based skid developed and tested at the NCCC. Table 1 lists the process parameters relevant to the GPS process.

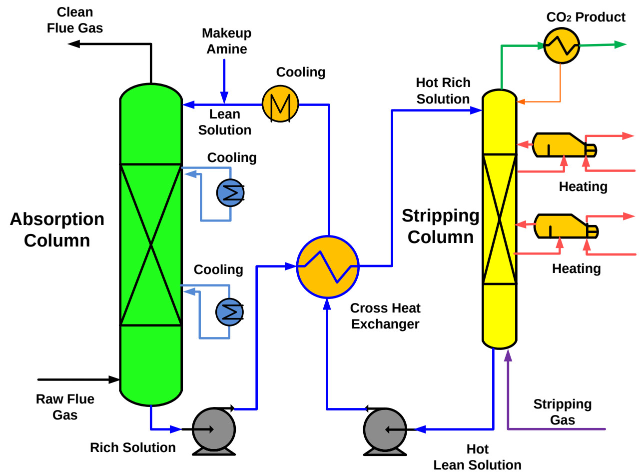

Figure 1: GPS-based absorption/stripping process

Figure 2: GPS-based skid used for bench-scale slipstream testing at NCCC

TABLE 1: SOLVENT PROCESS PARAMETERS

Pure Solvent	Units	Current R&D Value		Target R&D Value
Molecular Weight	mol^{-1}	112.4		112.4
Normal Boiling Point	°C	226.8		226.8
Normal Freezing Point	°C	4.4		4.4
Vapor Pressure @ 15 °C	bar	<1.3E-05		<1.3E-05
Manufacturing Cost for Solvent	$/kg	3		3
Working Solution				
Concentration	kg/kg	—		—
Specific Gravity (15 °C/15 °C)	—	1.06		1.06
Specific Heat Capacity @ STP	kJ/kg-K	ca. 3		ca. 3
Viscosity @ STP	cP	N/A		
Absorption				
Pressure	bar	1.01		1.01
Temperature	°C	40		40
Equilibrium CO_2 Loading	mol/mol	0.41		0.49
Heat of Absorption	kJ/mol CO_2	59.6		59.6
Solution Viscosity	cP	6.2		4
Desorption				
Pressure	bar	6		6
Temperature	°C	120		120
Equilibrium CO_2 Loading	mol/mol	0.19		0.19
Heat of Desorption	kJ/mol CO_2	58.5		58.5
Proposed Module Design		*(for equipment developers)*		
Flue Gas Flowrate	kg/hr		40	
CO_2 Recovery, Purity, and Pressure	%/%/bar	90%	>95%	6 bar
Absorber Pressure Drop	bar		0.05	
Estimated Absorber/Stripper Cost of Manufacturing and Installation	$\frac{\$}{kg/hr}$		—	

Definitions:

STP – Standard temperature and pressure (15 °C, 1 atm).

Pure Solvent – Chemical agent(s), working alone or as a component of a working solution, responsible for enhanced CO_2 absorption (e.g., the amine MEA in an aqueous solution).

Manufacturing Cost for Solvent – "Current" is market price of chemical, if applicable; "Target" is estimated manufacturing cost for new solvents, or the estimated cost of bulk manufacturing for existing solvents.

Working Solution – The solute-free (i.e., CO_2-free) liquid solution used as the working solvent in the absorption/desorption process (e.g., the liquid mixture of MEA and water).

Absorption – The conditions of interest for absorption are those that prevail at maximum solvent loading, which typically occurs at the bottom of the absorption column. These may be assumed to be 1 atm total flue-gas pressure (corresponding to a CO_2 partial pressure of 0.13 bar) and 40 °C; however, measured data at other conditions are preferable to estimated data.

Desorption **–** The conditions of interest for desorption are those that prevail at minimum solvent loading, which typically occurs at the bottom of the desorption column. Operating pressure and temperature for the desorber/stripper are process-dependent (e.g., an MEA-based absorption system has a typical CO_2 partial pressure of 1.8 bar and a reboiler temperature of 120 °C). Measured data at other conditions are preferable to estimated data.

***Pressure* –** The pressure of CO_2 in equilibrium with the solution. If the vapor phase is pure CO_2, this is the total pressure; if it is a mixture of gases, this is the partial pressure of CO_2. Note that for a typical PC power plant, the total pressure of the flue gas is about 1 atm and the concentration of CO_2 is about 13.2 percent. Therefore, the partial pressure of CO_2 is roughly 0.132 atm or 0.130 bar.

***Concentration* –** Mass fraction of pure solvent in working solution.

***Loading* –** The basis for CO_2 loadings is moles of pure solvent.

Other Parameter Descriptions:

***Chemical/Physical Solvent Mechanism* –** Pressurized stripping is a process applicable to different types of solvents. Chemistry of the GPS-based absorption/stripping process depends on the solvent used in the process. In the proposed research, a modified commercially-available amine solvent will be used. Therefore, the chemistry of the amine-based CO_2 capture process will apply to the GPS-based process.

The reaction kinetics of the GPS-based process also depends on the solvent selected. With the solvent currently selected, it is believed that the reaction kinetics of the modified commercially available solvent will perform better than the baseline monoethanolamine (MEA) process.

***Solvent Contaminant Resistance* –** Since the selected solvent is an amine-based solvent, it will share common issues that other amine-based solvents have. Sulfur oxide (SO_x) and nitrogen oxide (NO_x) could be the major contaminants in flue gas, which will be detrimental to all amine-based solvents, including the solvent used in this process. Similar to other amine-based solvents, pretreatment of flue gas will be required to minimize amine degradations.

***Solvent Foaming Tendency* –** The solvent is a commercially available solvent, with different strength. The solvent forming tendency should be manageable based on industrial experience.

***Flue Gas Pretreatment Requirements* –** Similar to other amine-based solvents, pretreatment of flue gas will be required to minimize amine degradations.

***Solvent Makeup Requirements* –** Solvent stability study has demonstrated that this commercially-available solvent will have solvent makeup rate of 1 kg solvent/tonne CO_2.

***Waste Streams Generated* –** Waste stream of the GPS-based process is also similar to other amine-based absorption/stripping processes. The main waste material is amine degradation products.

Process Design Concept – Flowsheet/block flow diagram of the GPS process is shown in Figure 1. It is clear that the GPS process is virtually the same as a conventional absorption/stripping process except the two unique innovations: (1) using two side heat exchangers to replace a bottom reboiler, and (2) introducing a stripping gas (N_2 or other inert gas) into the GPS column from the bottom. This process configuration will reduce stripping heat significantly.

Proposed Module Design – Unless noted, flue gas feed pressure is 1.014 bara, temperature is 57 °C, and composition leaving the flue gas desulfurization (FGD) unit (wet basis) should be assumed:

Pressure	Temperature	Composition						
		vol%					ppmv	
bara	°C	CO_2	H_2O	N_2	O_2	Ar	SO_x	NO_x
1.014	57	13.17	17.25	66.44	2.34	0.80	42	74

technology advantages

- The use of off-the-shelf process equipment will accelerate process development.
- The use of absorption/stripping technology would be suitable for low-cost, large-scale applications.
- The higher stripper operating pressure reduces the stripping heat requirement and subsequent compression work. As a result, GPS process offers higher energy efficiency.

- The GPS technology is flexible in terms of operating pressures and temperatures, and is applicable to different types of solvents.

R&D challenges

The major challenge of the GPS-based process is its capital cost. The optimal GPS-based process has almost the same capital cost as the baseline process. New process equipment, which can significantly reduce capital cost, is needed to commercialize the GPS technology.

status

The project was completed on September 30, 2015. Carbon Capture Scientific and their partners determined that a combination of experimental, computer simulation, and techno-economic analysis was effective to identify optimal process configurations and operating conditions for the GPS technology and that the GPS-based post-combustion capture process is energy-efficient and cost-effective compared with the benchmark MEA process. Integrating the GPS process into a 550-MW_e PC-fired power plant will increase cost of electricity approximately 23 percent less than that for the benchmark MEA process.

available reports/technical papers/presentations

Shiaoguo (Scott) Chen, "Development of a Novel Gas Pressurized Stripping (GPS)-Based Technology for CO_2 Capture from Post-Combustion Flue Gases," Final Scientific/Technical Report, October 2015. *https://www.osti.gov/scitech/servlets/purl/1233208*.

Shiaoguo (Scott) Chen, "Development of a Novel Gas Pressurized Stripping (GPS)-Based Technology for CO_2 Capture from Post-Combustion Flue Gases," Project Closeout Meeting, Pittsburgh, PA, December 2015. *https://www.netl.doe.gov/File%20Library/Research/Coal/carbon%20capture/post-combustion/FE0007567-Final-Review-Presentation-12-18-2015.pdf*.

Shiaoguo (Scott) Chen, "Development of a Novel Gas Pressurized Stripping (GPS)-Based Technology for CO_2 Capture from Post-Combustion Flue Gases," 2015 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, June 2015. *https://www.netl.doe.gov/File%20Library/Events/2015/co2captureproceedings/S-Chen-CCS-Gas-Pressurized-Stripping.pdf*.

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"Development of a Novel Gas Pressurized Stripping Process-Based Technology for CO_2 Capture," Project Kick-Off Meeting Presentation, November 2011. *http://www.netl.doe.gov/File%20Library/Research/Coal/ewr/CO2/development-novel-gas-pressurized-stripping-kickoff-nov2011.pdf*.