CO_2 Capture from IGCC Gas Streams Using the AC-ABC Process

primary project goals

SRI International (SRI)'s goal was development of a carbon dioxide (CO_2) capture technology for integrated gasification combined cycle (IGCC)-based power plants that uses a high-capacity and low-cost aqueous solution containing ammonium carbonate (AC) that reacts with CO_2 to form ammonium bicarbonate (ABC). SRI partnered with Bechtel Hydrocarbon Technology Solutions (BHTS) to use the Bechtel Pressure Swing Claus (BPSC) process to remove sulfur species from the recovered CO_2 stream.

technical goals

- Test the technology on a bench-scale batch reactor to validate the concept.
- Determine the optimum operating conditions for a small pilot-scale reactor.
- Design and build a small pilot-scale reactor capable of continuous, integrated operation.
- Perform pilot-scale tests to evaluate the process in a coal gasifier environment.
- Perform a technical and economic evaluation of the technology.

technical content

The technology is based on the use of an aqueous ammoniated solution containing AC, which reacts with CO_2 to form ABC.

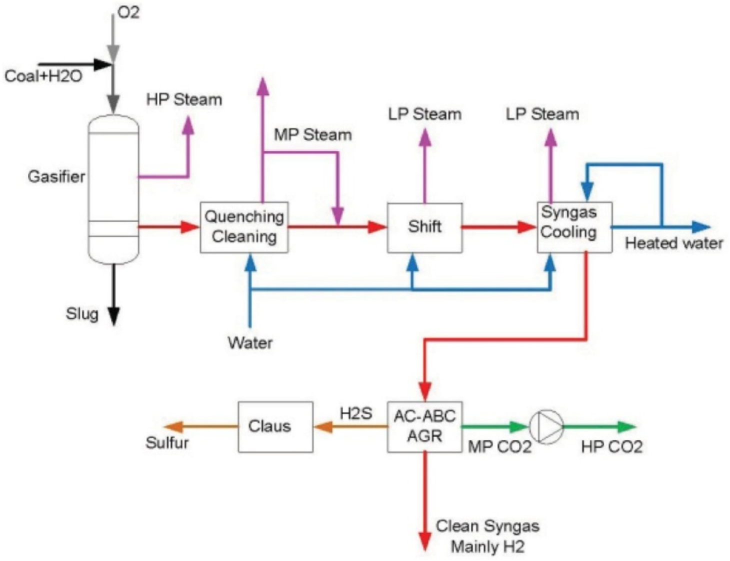

Figure 1: Acid gas removal in a gasification system

The concentrated ammoniated solution is used to capture CO_2 and hydrogen sulfide (H_2S) from synthesis gas (syngas) at high pressure. This high-pressure separation technique reduces the size of the CO_2 stripper, the CO_2 compression needs, and the

technology maturity:

Pilot-Scale, Actual Syngas (equivalent to 0.15 MW_e)

project focus:

CO_2 Capture Using AC-ABC Process

participant:

SRI International

project number:

FE0000896

predecessor projects:

N/A

NETL project manager:

Steven Mascaro
steven.mascaro@netl.doe.gov

principal investigator:

Anoop Nagar
SRI International
anoop.nagar@sri.com

partners:

Bechtel Hydrocarbon Technology Solutions, Inc.; EIG, Inc.; National Carbon Capture Center

start date:

09.30.2009

percent complete:

100%

electric power consumption relative to capture at lower syngas pressures. Figure 1 depicts the AC-ABC acid gas removal process in the larger context of a coal gasification and syngas cleanup system.

Figure 2 depicts the flows within the AC-ABC process, showing how acid gases are removed from the syngas in the absorber column, and how they are recovered as a separate gas stream in the stripping column. AC is a low-cost and readily available reagent with high net CO_2 loading capacity, requiring relatively low circulation of solvent between the CO_2/H_2S absorber and CO_2/H_2S stripper. The ammonium carbonate is highly selective to CO_2 and H_2S at the lower temperatures of the gas and solvent in the absorber (solvent entering column at 85 °F), while the solubility of hydrogen (H_2), carbon monoxide (CO), and methane (CH_4) in the absorber solution is extremely low, resulting in minimal losses of syngas species in the absorber. Rich solvent exiting the absorber is regenerated in the stripping column by increasing its temperature (solution entering column at 250 °F), causing the CO_2 and H_2S to evolve as a relatively pure gas stream from the stripper. The pressure is relatively constant in this cycle, with only the temperature being varied, classifying this a temperature-swing absorption cycle for acid gas removal from syngas.

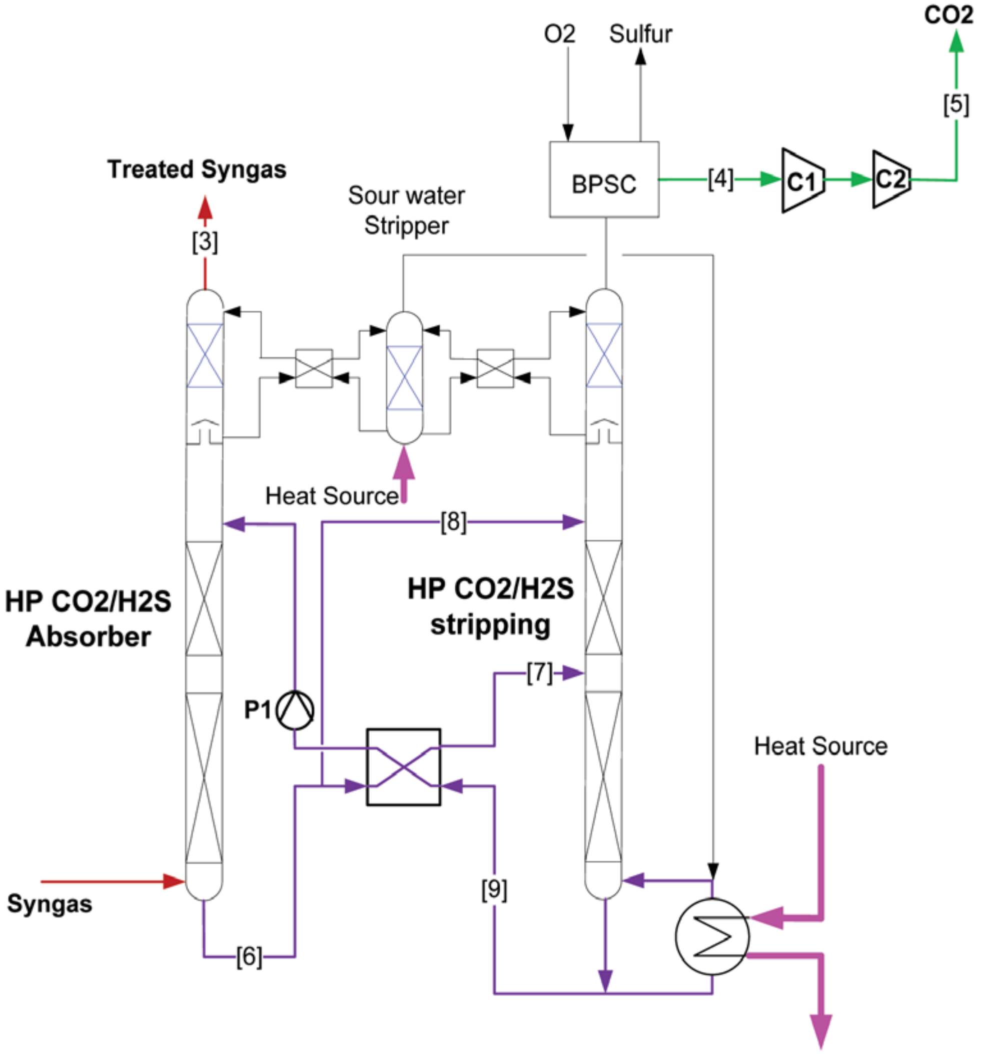

Figure 2: Schematic of the CO_2 and H_2S capture system

Because the AC-ABC process removes a mixture of CO_2 and H_2S, it is necessary to separate the H_2S to enable utilization or storage of the CO_2. Accordingly, the BPSC process was chosen for this purpose downstream from the AC-ABC unit. BPSC is a high-pressure, sub dew point Claus system which recovers H_2S directly from an acid gas stream in the form of elemental molten sulfur, using SO_2 as an oxidant. In this technology, multiple sub dew point reactors are used in rotation (Lead/Lag/Regeneration) similar to a molecular sieve dehydration unit, a pressure swing absorption unit, or a low-pressure sub dew point Claus system. BPSC allows recovery of sulfur species as elemental sulfur while maintaining system pressure. Due to the higher pressures compared to traditional Claus units, equipment size is reduced. Figure 3 shows the basic process scheme of the BPSC system.

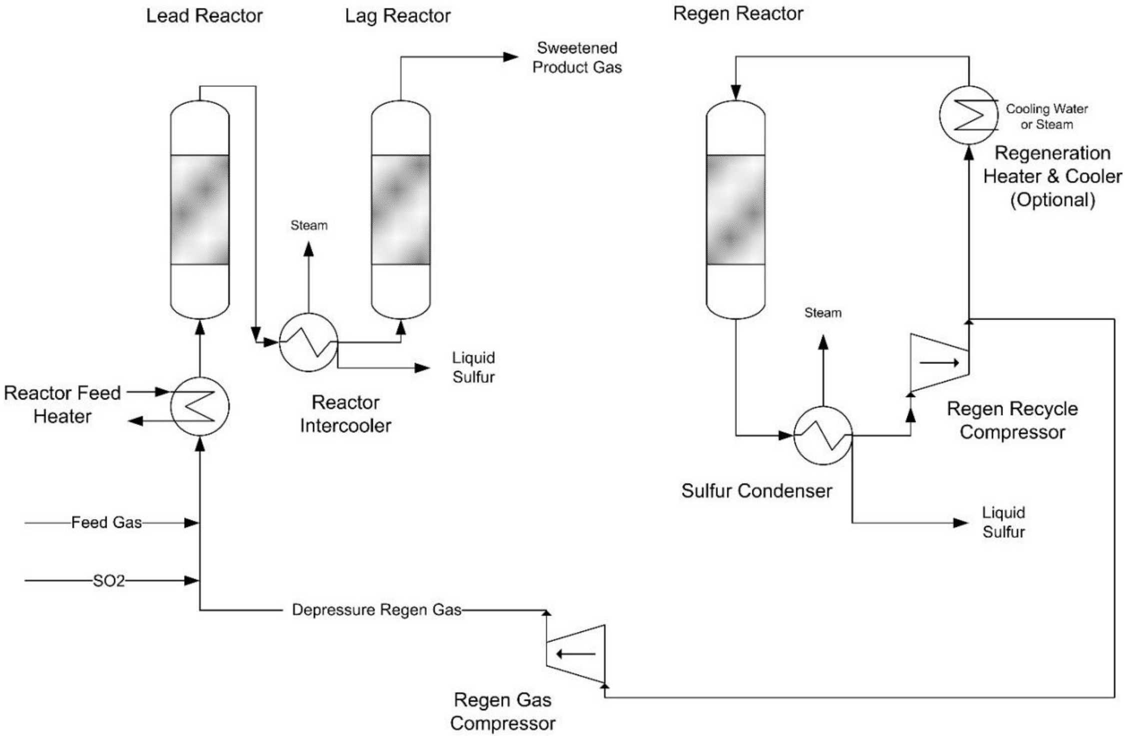

Figure 3: Schematic of the Bechtel pressure swing Claus H_2S removal system

In the BPSC process, SO_2 (produced by oxidizing some of the product sulfur) is introduced to the acid gases ("feed gas") and they are heated indirectly by steam in the "reactor feed heater". Then the mixture is fed to the first or primary on-line reactor ("primary reactor"), where most of the H_2S, carbonyl sulfide (COS), and SO_2 are converted to sulfur and adsorbed on the catalyst. The gas flows through a cooler ("reactor intercooler"), where it is cooled by generating steam. Provisions are made to accommodate any sulfur that may condense at this location. Any recovered sulfur drains to a sulfur pit, and the vapor goes to the next reactor ("secondary reactor/sulfur trap"), which acts as a sulfur trap/guard bed. The product gas is returned to the facility for compression. After about 8–12 hours online, the primary reactor is rotated to regeneration, the secondary reactor moves up to the primary position, and the regenerated reactor is switched to the secondary reactor position. The sulfur-loaded bed is partially regenerated by pressure let down. Flash gas passes through a sulfur condenser and is recompressed in the Regen Recycle Compressor and Regen Gas Compressor prior to being mixed into the BPSC feed stream. There is a heating and cooling cycle ("Regeneration Heater & Cooler") using recycled sweep gas to complete the reactor regeneration.

In 2016, SRI International and EIG Inc. were awarded a patent on the technology for simultaneous high-efficiency capture of CO2 and H2S from pressurized gas, which is at the core of the AC-ABC Process. For further information, refer to U.S. Patent No. 9,463,416 B2, dated October 11, 2016.

TABLE 1: SOLVENT PROCESS PARAMETERS

Pure Solvent	Units	Current R&D Value	Target R&D Value
Molecular Weight	mol^{-1}	nominal 18	nominal 18
Normal Boiling Point	°C	varies with pressure: 100 °C at 1 atm	varies with pressure: 100 °C at 1 atm
Normal Freezing Point	°C	nominal 0 °C, varies with composition	nominal 0 °C, varies with composition
Vapor Pressure @ 15°C	bar	NH_3 vapor pressure varies with composition and temperature	NH_3 vapor pressure varies with composition and temperature
Manufacturing Cost for Solvent	$/kg	—	cost of anhydrous ammonia typically $200–$400/ton
Working Solution			
Concentration	kg/kg	0.1 kg NH_3/kg	0.15 kg NH_3/kg
Specific Gravity (15 °C/15 °C)	-	1.1	1.1
Specific Heat Capacity @ STP	kJ/kg-K	3.5	3.5
Viscosity @ STP	cP	nominal 1	nominal 1
Absorption			
Pressure	bar	20	30
Temperature	°C	25	25–40
Equilibrium CO_2 Loading	mol/mol	varies with the composition of the solution	varies with the composition of the solution
Heat of Absorption	kJ/mol CO_2		40-60
Solution Viscosity	cP	nominal 1	nominal 1
Desorption			
Pressure	bar	30	30
Temperature	°C	<200°C	—
Equilibrium CO_2 Loading	mol/mol	varies with the composition of the solution	varies with the composition of the solution
Heat of Desorption	kJ/mol CO_2	—	—
Proposed Module Design		*(for equipment developers)*	
Syngas Flowrate	kg/hr	225	
CO_2 Recovery, Purity, and Pressure	% / % / bar	90% >95% 30 bar	
Absorber Pressure Drop	bar	<1 bar	
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 monoethanolamine [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.

Concentration – Mass fraction of pure solvent in working solution.

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

Estimated Cost – Basis is kg/hr of CO_2 in CO_2-rich product gas; assuming targets are met.

Other Parameter Descriptions:

Chemical/Physical Solvent Mechanism –

$NH_4OH + CO_2 \leftrightarrow NH_4HCO_3$

$(NH_4)_2CO_3 + CO_2 + H_2O \leftrightarrow 2NH_4HCO_3$

$NH_4(NH_2CO_2) + CO_2 + 2H_2O \leftrightarrow 2NH_4HCO_3$

Solvent Contaminant Resistance – The solvent is expected to be resistant to several contaminants nominally present in an IGCC gas stream. Hydrogen sulfide reacts with the solvent, but it can be removed during the regeneration. The ammonia (NH_3) in the IGCC may negate any NH_3 loss from the solvent. The resistance of the solvent to trace metals is not known yet.

Solvent Foaming Tendency – Solvent foaming tendency was not observed in the bench-scale tests.

Syngas Pretreatment Requirements – The IGCC gas stream needs to undergo a water gas shift (WGS) reaction to convert CO to CO_2 and to be cooled to a temperature of 25–50 °C.

Solvent Makeup Requirements – The AC is a readily available commodity chemical, and the makeup requirements are estimated to be small. However, the actual amount will be determined in the field test.

Waste Streams Generated – Ammonium sulfate solution from the capture of trace residual NH_3 in the gas.

Process Design Concept – See Figures 1–3.

Proposed Module Integration – Note the module location, as well as the pressure, temperature, and composition of the gas entering the module.

		Composition						
Pressure	Temperature	vol%						ppmv
psia	°F	CO_2	CO	CH_4	N_2	H_2	Ar	H_2S
185	68	13.4	0.03	0.6	74.4	10.1	0.6	2000

technology advantages

- Low-cost and stable reactive solution/solvent—low ammonia loss demonstrated in testing.
- Ammoniated solution is very effective in rapid absorption of CO_2 at elevated pressure—CO_2 capture efficiency greater than 99 percent demonstrated in testing.
- The reactive ammoniated solution has a high CO_2 loading capacity (12 percent CO_2 effective loading).
- H_2S can be simultaneously absorbed along with CO_2 in a single absorber column—H_2S capture efficiency greater than 99 percent demonstrated in testing.

- The absorption/loss of fuel gas species like H_2, CO, and CH_4 was very low as shown in testing—therefore high conversion of CO in the syngas is not required to achieve 90 percent reduction of carbon emissions.
- CO_2 stripping in the AC-ABC process can be accomplished at elevated pressures in the range of 20–50 bar, resulting in a 3–7.5 pressure ratio to compress the gas to the pipeline pressure of 150 bar pressure—i.e., the availability of regenerated CO_2 at elevated pressure significantly reduces the compressor requirements for CO_2 sequestration.
- The AC-ABC process does not require compressors other than the CO_2 compressor.
- Both the absorber and regenerator are operated at similar elevated pressure, reducing the need for pumping solvents across pressure boundaries.
- Hot syngas from the shift reactor can be used as the main heat source for the CO_2 stripping, reducing the power output penalty.
- The BPSC process removes H_2S from the high-pressure CO_2 (or syngas) stream with minimal reduction in pressure, which reduces the power output penalty.
- The BPSC process combines the function of three units (solvent, Claus, and Claus tail gas) into one. The thermal oxidizing unit needed for the traditional approach is not needed with BPSC, reducing total carbon footprint.

R&D challenges

- Possible sulfating problem on beds of BPSC process catalyst.
- Difficulty in measurement/quantification of sulfur produced in the BPSC process at pilot scale.
- Difficulties in engineering packing or trays to effectively control ammonia emissions from the absorber at pilot scale.

status

The project was completed in September 2016. In the culmination of project activities, a 0.15-megawatt electric (MW_e) integrated pilot plant was constructed and operated, processing 500 lb/hr of shifted syngas from an air blown gasifier at the National Carbon Capture Center in Wilsonville, Alabama, with total testing duration of over 700 hours. This successfully demonstrated use of the AC-ABC process for carbon dioxide and sulfur capture from actual coal-derived syngas. System availability was considered to be favorable, even at the pilot-scale level.

The results of the techno-economic analysis (with baseline case 750-MW IGCC plant using CO_2 capture using conventional Selexol and traditional Claus plant) indicate that the increase in cost of electricity (COE) with the AC-ABC process will be ~30 percent, and the cost of CO_2 captured is projected to be less than $27/metric ton of CO_2 while meeting DOE's 90 percent CO_2 capture goal.

available reports/technical papers/presentations

Nagar, A. et al., "*CO_2 Capture from IGCC Gas Streams Using AC-ABC Process,*" Final Report, SRI Project P19207 and P21321, Cooperative Agreement No. DE-FE0000896, SRI International, Menlo Park, CA, 16 February 2017.

"*CO_2 Capture from IGCC Gas Streams Using AC-ABC Process*," presented at the 2014 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, July 2014.

"*CO_2 Capture from IGCC Gas Streams Using AC-ABC Process*," presented at the 2013 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, July 2013.

"*CO_2 Capture from IGCC Gas Streams Using AC-ABC Process*," presented at the 2012 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, July 2012.

"*CO_2 Capture from IGCC Gas Streams Using AC-ABC Process*," presented at the 2011 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, August 2011.

"*CO_2 Capture from IGCC Gas Streams Using AC-ABC Process*," presented at the 2010 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, September 2010.

"CO_2 Capture from IGCC Gas Streams Using the AC-ABC Process," presented at the Pre-Combustion CO_2 Capture Kick-Off Meetings, Pittsburgh, PA, November 2009.

"Analysis of SRI AC-ABC and Bechtel Pressure Swing Claus Technologies for Pre-Combustion Carbon Capture," presented at the Eleventh Annual Conference on Carbon Capture, Utilization and Sequestration, Pittsburgh, PA, May 2012.

"Bechtel Pressure Swing Claus Sulfur Recovery," presented at the International Pittsburgh Coal Conference, Pittsburgh, PA, September 2009.