APPENDIX B: CARBON DIOXIDE CAPTURE TECHNOLOGY SHEETS

PRE-COMBUSTION SOLVENTS

CO_2 CAPTURE FROM IGCC GAS STREAMS USING AC-ABC PROCESS

Primary Project Goals

SRI International is developing, for integrated gasification combined cycle (IGCC)-based power plants, a carbon dioxide (CO_2) capture technology based on the use of a high-capacity and low-cost aqueous ammoniated solution containing ammonium carbonate (AC), which reacts with CO_2 to form ammonium bicarbonate (ABC).

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 on 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.

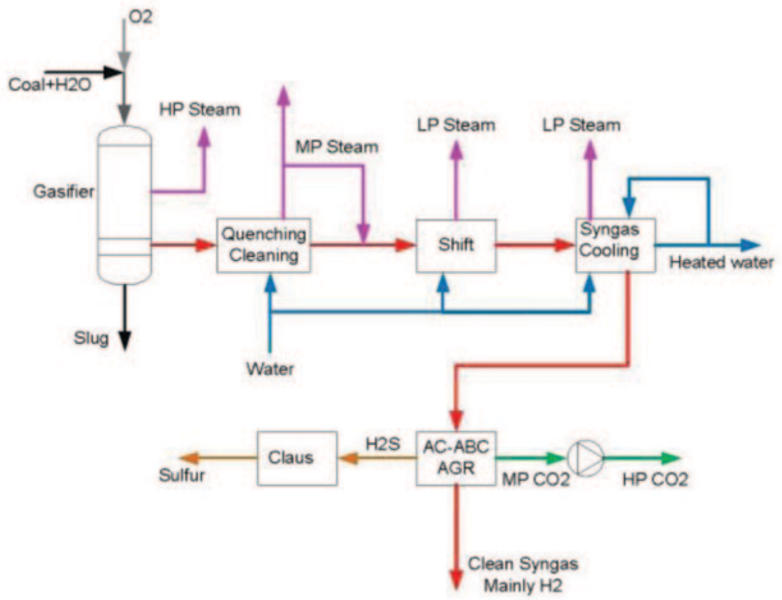

Figure 1: Acid Gas Removal in Gasification System

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

Technology Maturity:

Pilot-scale using actual syngas

Project Focus:

Ammonium Carbonate

Participant:

SRI International

Project Number:

FE0000896

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Performance Period:

9/30/09 – 3/31/12

tion. AC has high net CO_2 loading, is a low-cost and readily available reagent, and requires little solvent makeup; the solubility of hydrogen (H_2), carbon monoxide (CO), and methane (CH_4) in absorber solution is extremely low.

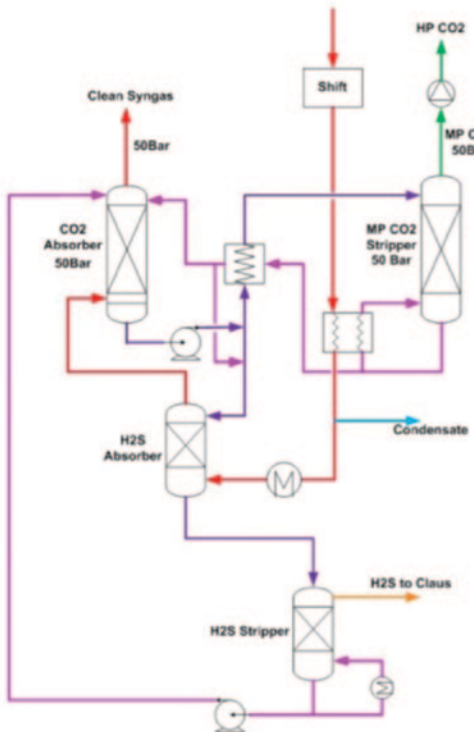

Figure 2: Schematic of the CO_2 and H_2S Capture System

The project, in its first phase, has constructed a bench-scale batch reactor unit to test the technology at SRI's facility in California. Testing is being done to validate the concept and to determine the optimum operating conditions.

Absorber testing is being done to first determine the solubility of shifted-gas components [H_2, CO, nitrogen (N_2), argon (Ar)], then determine the reactivity of CO_2, H_2S, and carbonyl sulfide (COS); mixed-gas testing will determine the relative reaction kinetics.

Regenerator testing is being done to determine CO_2 and H_2S release characteristics, as well as the relative kinetics of CO_2 and H_2S release. Optimal operating conditions derived in bench-scale testing will be carried over into a pilot-scale test.

Pilot-scale testing will be performed on a slip stream of Great Point Energy's 1 ton/day pilot gasifier located at Brayton Point, MA. SRI will design and construct a pilot-scale continuous, integrated test system. The pilot-scale test will emphasize stability of integrated operation. The tests will be of longer duration, about six to eight times longer total test time than with the simulated tests at SRI. The effects of trace contaminants will be observed, as the pilot tests will use a gas stream from an operating gasifier that has undergone minimum cleanup and will contain trace contaminants.

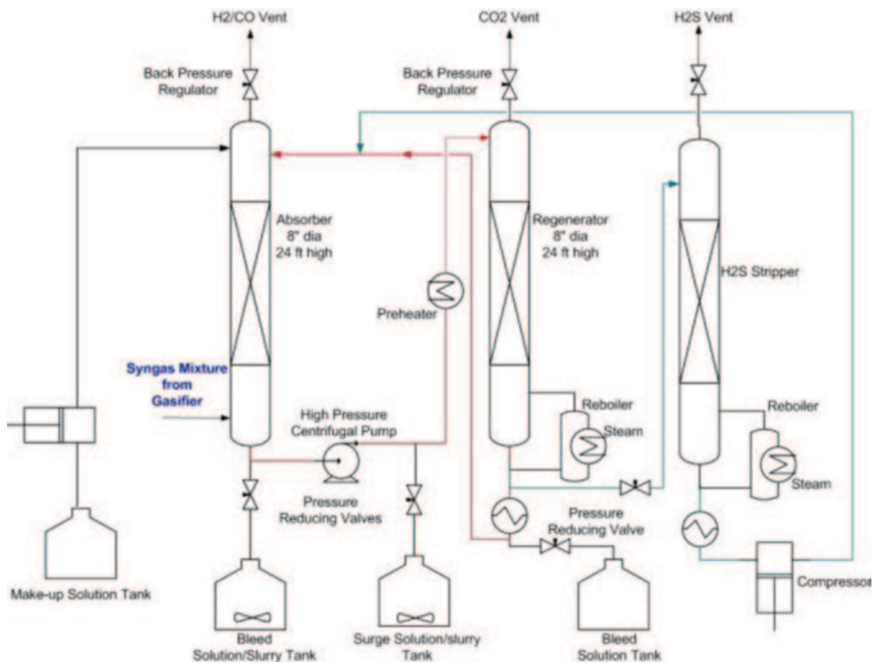

Figure 3: Pilot-Scale Integrated Testing (Preliminary)

A technical and economic analysis is underway using Aspen modeling to generate the equipment sizing and heat and material flows; DOE cost models; and a base case, 750-MW nominal IGCC plant without CO_2 capture to compare the AC-ABC process with a similar-size plant using CO_2 capture with a Selexol subsystem.

Table 1: Solvent Parameters

	Parameter	Current R&D Value	Target R&D Value
Solvent Properties	Type of solvent	Aqueous ammoniated solution	Aqueous ammoniated solution
	Molecular weight	Nominal 18	Nominal 18
	Boiling point (°C)	Varies with pressure; 100 °C at 1 atm	Varies with pressure; 100 °C at 1 atm
	Heat of reaction (kJ/mole CO_2)	40–60 depending on the NH_3/CO_2 ratio	40–60
	CO_2 loading/working capacity[1], wt%	10	20
	Solvent concentration to stripper (mol/liter)	6 M NH_3	8 M NH_3
	Heat capacity of solution (kJ/K/kg)	3.5	3.5
	Viscosity, cP	1	1
Operating Conditions	Absorption temperature, °C	25	25–40
	Absorption pressure, atm	20	50
	CO_2 capture efficiency, %	>90	>90
	Regeneration method	Heating with steam	Heating with steam
	Regeneration temperature, °C	N/A	150
	Regeneration pressure, atm	N/A	50
Heat Integration	Required regeneration steam temperature, °C	120	170
Miscellaneous	Solvent make-up rate, kg/kg CO_2	N/A	N/A
Product Quality	CO_2 purity, %	>98	98.1
	N_2 concentration, %	N/A	1.9
	Other contaminants, %	N/A	0.01
Process Performance	Electricity requirement, kJ/kg CO_2	N/A	17.7
	Heat requirement, kJ/kg CO_2	N/A	620.6
	Total energy (electricity equivalent), kJ/kg CO_2	N/A	638.3

Note:

1. Working capacity is the loading difference CO_2-rich solution before and after it is regenerated.

Equations Describing Chemical Reaction:

$NH_4OH + CO_2 = NH_4HCO_3$

$(NH_4)_2CO_3 + CO_2 + H_2O = 2NH_4HCO_3$

$NH_4(NH_2CO_2) + CO_2 + 2H_2O = 2NH_4HCO_3$

$NH_4HCO_3 = NH_4HCO_3$ (precipitate)

Solvent Reaction Kinetics: The absorption of CO_2 by the ammoniated solution is proportional (1st order) to the CO_2 partial pressure. Preliminary experiments confirm this behavior. The kinetics of CO_2 absorption is expected to be rapid at the elevated pressures and high CO_2 concentrations expected in the IGCC gas stream downstream of the water gas shift (WGS) reactors.

Solvent Heating/Cooling Method: During regeneration, the liquid is heated by steam using a reboiler. In the absorber, the liquid is cooled using a heat exchanger and a coolant from a direct contact cooler.

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.

Flue Gas Pretreatment Requirements: The IGCC gas stream needs to undergo WGS reaction to convert CO to CO_2 and to be cooled to a temperature of 25 °C to 50 °C.

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

Technology Advantages

- Low-cost and stable reactive solution.
- Reactive solution has a high CO_2 loading capacity due, in part, to the formation of ABC solids during absorption.
- Optimum operating pressure, including CO_2 output stream, is expected to be between 200 and 700 pounds per square inch (psi), resulting in lower compression costs than conventional technologies.

R&D Challenges

- Precipitation of solids could potentially foul packing and heat exchanger surfaces.
- Absorber operation at an elevated temperature could create excessive residual ammonia in the fuel gas stream leaving the absorber.
- Adequate separation of H_2S and CO_2 in the regenerator gas.

Results To Date/Accomplishments

- Bench-scale mixed gas batch tests, in various gas compositions, were conducted. Carbon dioxide and H_2S capture rates were experimentally determined as a function of temperature, pressure, and solution and gas compositions. Data from regenerator experiments were used to determine the optimum regenerator conditions for the release of CO_2 and H_2S exclusively.
- Bench-scale simple gas mixture batch test runs were conducted. It was observed that:
  - CO_2 and H_2S are absorbed in the system at pressures between 200 and 300 psi and temperatures between 20 and 60 °C.
  - The absorption of CO_2 in the ammoniated solution was found to be efficient, capable of capturing >95% of the feed CO_2 at a temperature above ambient.
  - Absorption tests with H_2S also showed that the ammoniated solutions were highly effective in absorbing H_2S and efficiencies as high as 95% were achieved.
  - The ratio of CO_2/NH_3 (R' value) in solution has a major influence on the rate of both H_2S and CO_2 absorption; the rate increased with decreasing value of the parameter.
  - The total pressure had a positive effect on the rate, as expected. The NH_3 concentration of the solution had only a minor effect, indicating that high CO_2 loading of the solution can be achieved without a significant effect on the absorption efficiency.
- Bench-scale regenerator tests were conducted with 10–20 wt% CO_2 loaded ammoniated solutions. Regeneration tests showed that:
  - CO_2 can be released from the solution under conditions of 450 psi and 125 °C.
  - The regeneration tests showed that ammoniated solutions suitable for absorption with high NH_3/CO_2 ratios can be generated at moderate temperatures and at elevated pressures.

In summary, the bench-scale tests demonstrated an efficient absorption of CO_2 and H_2S at elevated pressures without the need for sub-ambient operation. High-pressure CO_2 and concentrated H_2S streams can be released during the regeneration of loaded solution.

- Preliminary economic analysis using simulations was performed and indicates that the AB-ABC capture process requires less parasitic electric power consumption and has a lower capital cost than the Selexol process. The cost of CO_2 capture by the AC-ABC process was estimated for a 750-MWe IGCC plant.

Next Steps

- Perform preliminary process modeling.
- Prepare for pilot scale.

Available Reports/Technical Papers/Presentations

CO_2 Capture from IGCC Gas Streams Using AC-ABC Process; Presentation at the 2010 NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, September 13–17, 2010. http://www.netl.doe.gov/publications/proceedings/10/co2capture/presentations/thursday/Gopala Krishnan - FE0000896.pdf

CO_2 Capture from IGCC Gas Streams Using the AC-ABC Process; Presentation at the Pre-Combustion CO_2 Capture Kick-off Meetings, Pittsburgh, PA, November 12–13, 2009; Available at the NETL website.