InnoSepra

Lab and Bench-Scale Testing of CO_2 Capture Using Physical Sorbents

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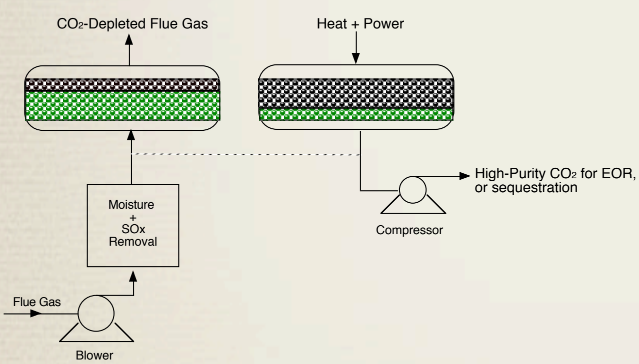
Executive Summary

- Physical sorption to produce dry CO_2 at high purity (>98%) and high recovery (>90%) from the flue gas
- An impurities removal stage followed by a CO_2 adsorption stage
  - Both the stages have been extensively tested in the lab and in the field (up to 100 scfm flue gas flow) for over 6 years
- Potential for more than 40% reduction in the capital and more than 40% reduction in parasitic power for CO_2 capture compared to MEA
- The estimated total energy required, excluding compression, is 450-500 kcal/kg of CO_2
  - Potential to provide **CO_2 at a cost (<$40/ton) and quality (<1 ppm H_2O, <1 ppm SO_X, <10 ppm O_2) suitable for EOR applications**
- The DOE projects addressed various process risks and scale up issues through lab and field testing, process simulation, and techno-economic evaluation

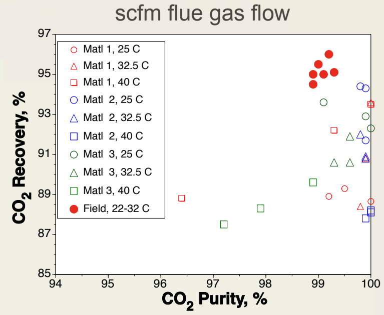
Process Overview



- Flue gas pretreatment to remove moisture and SO_X to < 1 ppm each, adsorption at 25-40°C and regeneration at ~100°C
- High purity CO_2 (>98% purity, <10 ppm O_2) at >90% recovery
- The key innovation is **the combination** of process and materials (physical sorbents) that provides performance similar to or better than reactive systems with a much lower energy penalty

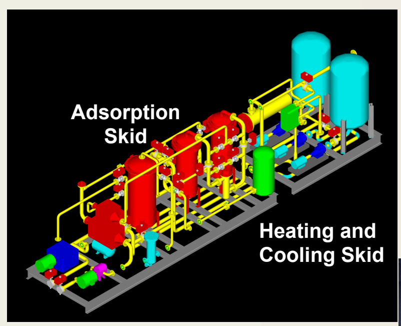
Lab and Field Testing Summary

- Lab testing for initial adsorbent screening
  - >90% CO_2 recovery, >99% CO_2 purity, 7-9 wt% net CO_2 capacity (~15% CO_2 in the feed)
  - Same or higher CO_2 purity and recovery as reactive sorbents
- The bench unit testing at NRG's Indian River, DE plant
  - The feed to bench unit saturated at 60°C, about 50 ppm SO_2, and 10-12% CO_2
  - Eight weeks of testing with 22-32°C feed temperature, 80-100 scfm flue gas flow



Field performance better than the lab performance

- **8-10.5 wt% net CO_2 capacity in the field**
- **>94% CO_2 recovery, 98.5-99.5% CO_2 purity**



Skid Layout

Heating and Cooling Skid

Adsorption Skid

Techno-Economic Analysis (550 MMW SCPC Plant, 2012 Basis)

Estimated Capital Cost	$388 MM
Power consumption including compression	99 MW
Steam cost with capture (per 1,000 lbs)*	$8.60 **(+47%)**
Electricity cost with capture*	$0.095/kWh **(+48%)**
CO_2 production rate, million tons/yr	3.5
CO_2 Recovery Cost**	**$46/ton**

*Based on the DE-FOA-0000403 guidelines

**85% plant utilization factor. Includes capital charge, power, maintenance, and transportation cost

Comparison with MEA (2011 Cost Basis, Case 12)

- 44% lower capital compared to MEA excluding the CO_2 compressor
- 38% lower capital including the CO_2 compressor
- 18% parasitic power load compared to 28% parasitic power load for MEA

Potential Approaches for Further Cost Reduction

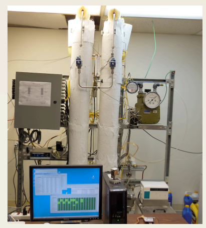
- The DOE bench scale project used particulate adsorbents which can be
  - **Subject to fluidization, attrition and higher pressure drop**
- The DOE SBIR project is looking at structured sorbents which are
  - **Not subject to fluidization, attrition and have a significantly lower pressure drop**
- The key goals for the project are
  - **Adsorption isotherms, process simulation and engineering design for CO_2 capture based on monoliths**
  - **Quantify benefits over MEA as well as with InnoSepra's process using particulate adsorbents with a detailed techno-economic analysis**
- The key benefits include
  - **Lower pressure drop, faster cycling and lower skid and shipping cost can overcome the higher cost of structured adsorbents**
  - **Potential for up to 10% reduction in CO_2 capture cost compared to particulate adsorbents**

Key Tasks for the Structured Adsorbent Project

- Vendor fabrication of sorbent modules
- Equipment modification and moisture removal testing
- Sorption isotherms and CO_2 capture testing
- Process simulation and engineering design
- Techno-economic analysis

Accomplishments So Far

- Structured sorbents for flue gas purification and CO_2 capture fabricated
- Breakthrough capacities determined in bed sizes up to 3" diameter



Lab Unit for Adsorbent Testing

- Capacities comparable to particulate adsorbents, much lower pressure drop (<1/5th)
- Process modeling and preliminary TEA indicating potential for CO_2 capture cost reduction

Overall Accomplishments

- The InnoSepra CO_2 capture process combines several innovative features to reduce the capital cost and parasitic power for CO_2 capture
- It is possible to obtain very high recovery (>90%), and high purity (>99%) CO_2 with physical sorbents while meeting the EOR/sequestration oxygen specification
  - **ΔH_{ads}<200 Kcal/kg, parasitic power <500 Kcal/kg**
  - **High net CO_2 capacity (>8 wt%)**
  - **<1 ppm each of SO_X and H_2O, 10-30 ppm O_2 in product CO_2**
- The capital cost and parasitic power estimates based on a detailed component level analysis indicate that we are close to DOE's LCOE target (<35% increase) and the CO_2 cost target (<$40/ton)
- Possible to obtain a CO_2 product suitable for EOR and sequestration
- Potential for further cost reduction through the use of structured sorbents