Development Novel Carbon Sorbents for Carbon Dioxide Capture

2010 NETL CO_2 Capture Technology Meeting

September 13-17, 2010 in Pittsburgh, PA.

Project Overview

- Participants:
  - SRI International, Menlo Park, CA
  - ATMI, Inc., Danbury, CT
  - DOE-National Energy Technology Center
- Period of Performance:
  - 10-1-2008 through 9-30-2011
- Funding:
  - U.S.: Department of Energy: $1.35 million
  - Cost share: $0.45 million
  - Total: $1.8 million

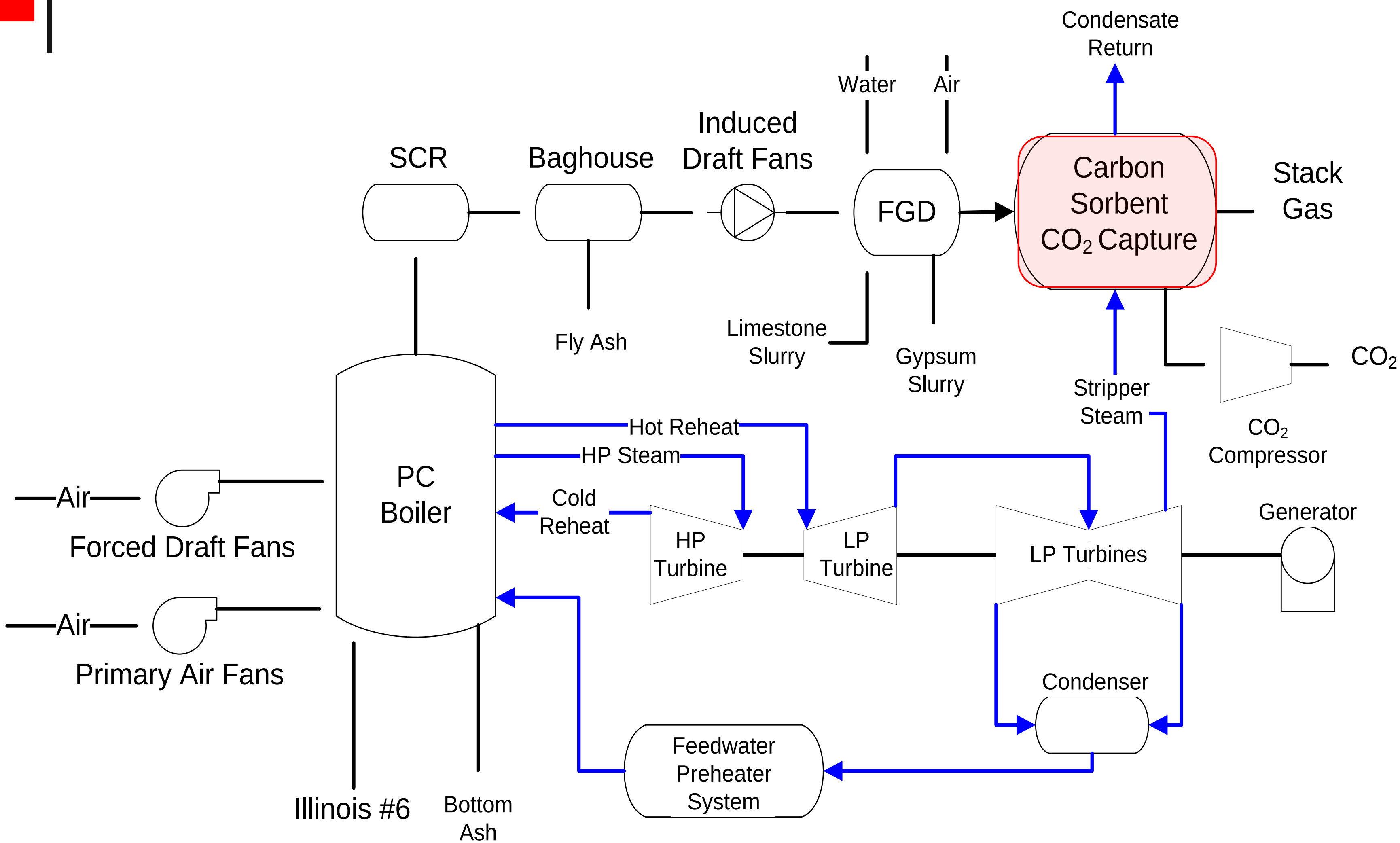
Basic Principles

- Adsorption of CO_2 from flue gas on a selective and high capacity carbon sorbent.
- Ability to achieve rapid adsorption and desorption rates (no solid state diffusion limit).
- Minimize thermal energy requirements
  - Relatively low desorption temperature.
  - Low heat of desorption.
- Ability to desorb as pure CO_2.

Project Objectives

- Validate the performance of novel carbon sorbents for CO_2 capture on a bench-scale system for post-combustion applications.
- Perform parametric experiments to determine the optimum operating conditions.
- Evaluate the technical and economic viability of the technology.
- Pilot-scale testing in a future phase

Block Flow Diagram



Advantages of the Carbon Sorbents

- Low cost and stable sorbent: In the operating range of 20° to 100°C, the carbon sorbent is very stable.
- Relatively high CO_2 loading (0.1 to 0.2 kg of CO_2 per kg of sorbent in pure CO2 at 1 atm).
- Low heat of absorption reaction
  - 25 to 28 kJ/mole CO_2
- Low heat requirements for regeneration: Sorbent can be regenerated to release CO_2 at atmospheric pressure in a temperature range of 80° to 100°C.

Technical Challenges

- Competitive adsorption of moisture and other flue gas components (SOx, and NOx).
- Adsorption temperature
  - Low temperature promotes adsorption
- Suitable reactor configuration for rapid cycling of the sorbent.
- Heat exchange between loaded (cold) and regenerated (hot) sorbents.

Project Tasks

- Determination of the relevant properties of the sorbent.
  - Surface area, heat of adsorption and desorption, compressive strength and attrition resistance, size and shape of the sorbent particles.
- Improvements to the properties of the sorbent.
  - Structural modification of the pore structure
  - Functionalizing the surface
- Bench-scale parametric testing of the sorbent for adsorption and regeneration:
  - Screening tests
  - Parametric tests
  - Long-term tests
- Process technical and economic analysis.

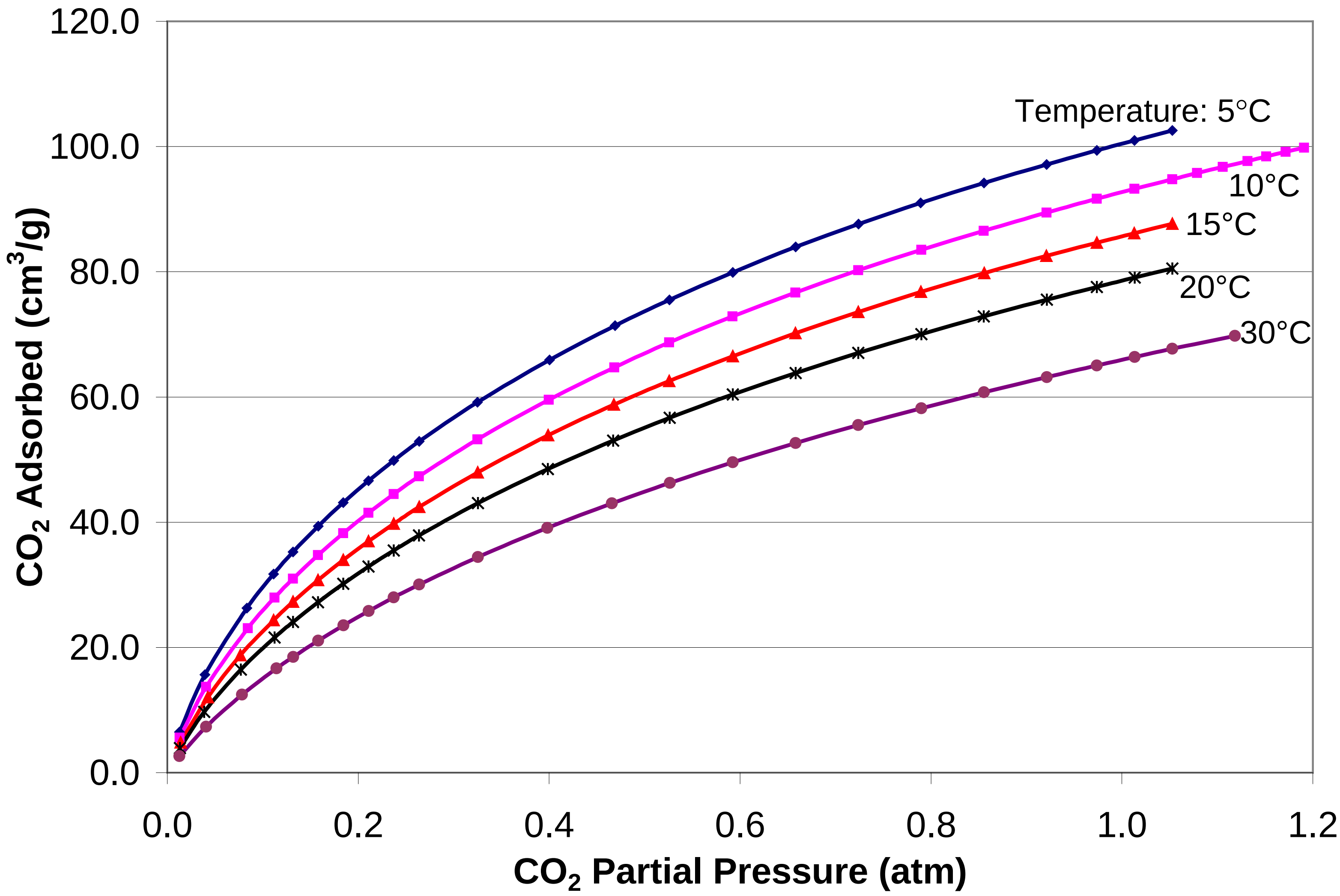
Determination of the Relevant Properties of the Sorbent

- Adsorption/desorption isotherms
  - Gives capacity of sorbent as a function of temperature and CO_2 pressure
- Heat of adsorption and desorption
  - Gives cooling requirements during adsorption and heating requirements during regeneration
  - Provides a guide to improving sorbent for CO_2 selectivity
- Compression strength and attrition resistance, particle size and shape
  - Determines suitability for use in industrially-relevant reactors

Physical Properties of the Sorbent

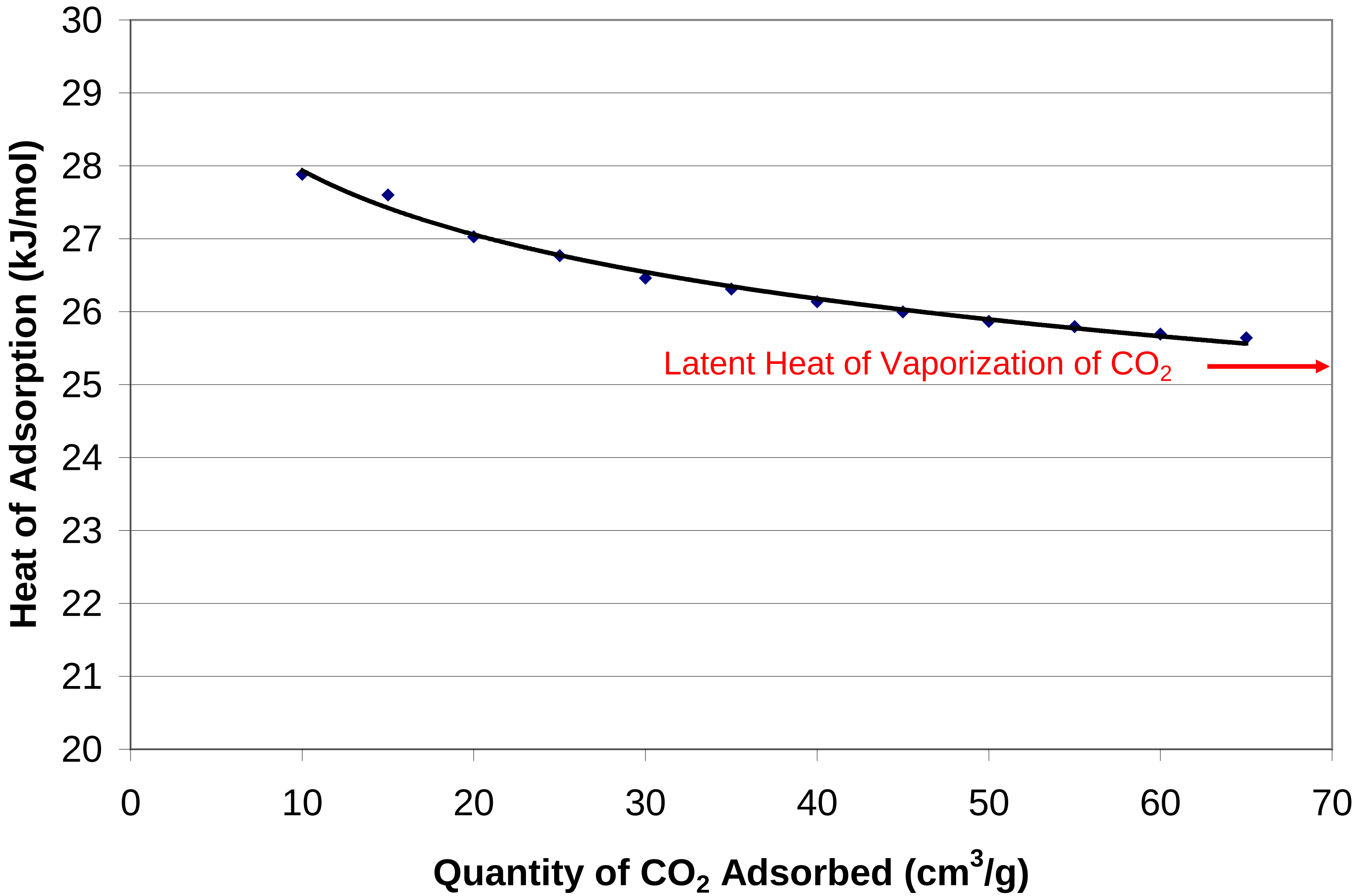
- A carbon sorbent currently manufactured by ATMI, Inc.
- High surface area (1300 m^2/g).
- Low heat capacity (1 J/g-°K).
  - 25% of the heat capacity of water.
- High thermal conductivity (0.82 W/m-°K)
  - 5 times higher than typical porous catalysts.
- Low density (1.1 kg/liter).
- Unusually tough for a high surface area porous solid.

CO_2 Adsorption Isotherms



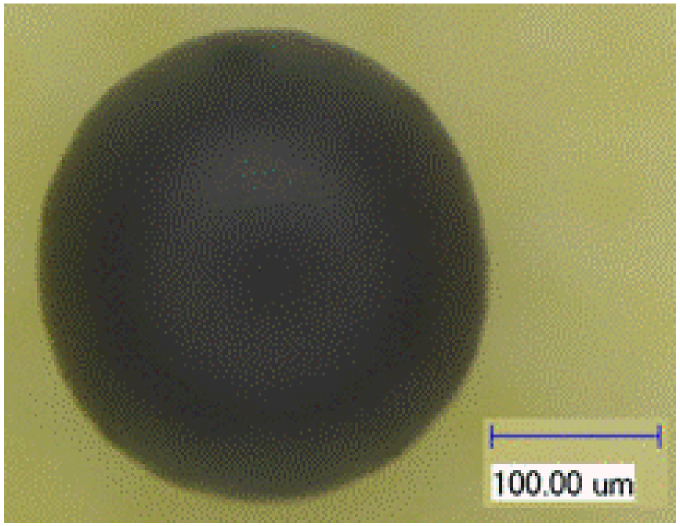
100 cm^3/g = 20 wt% CO_2

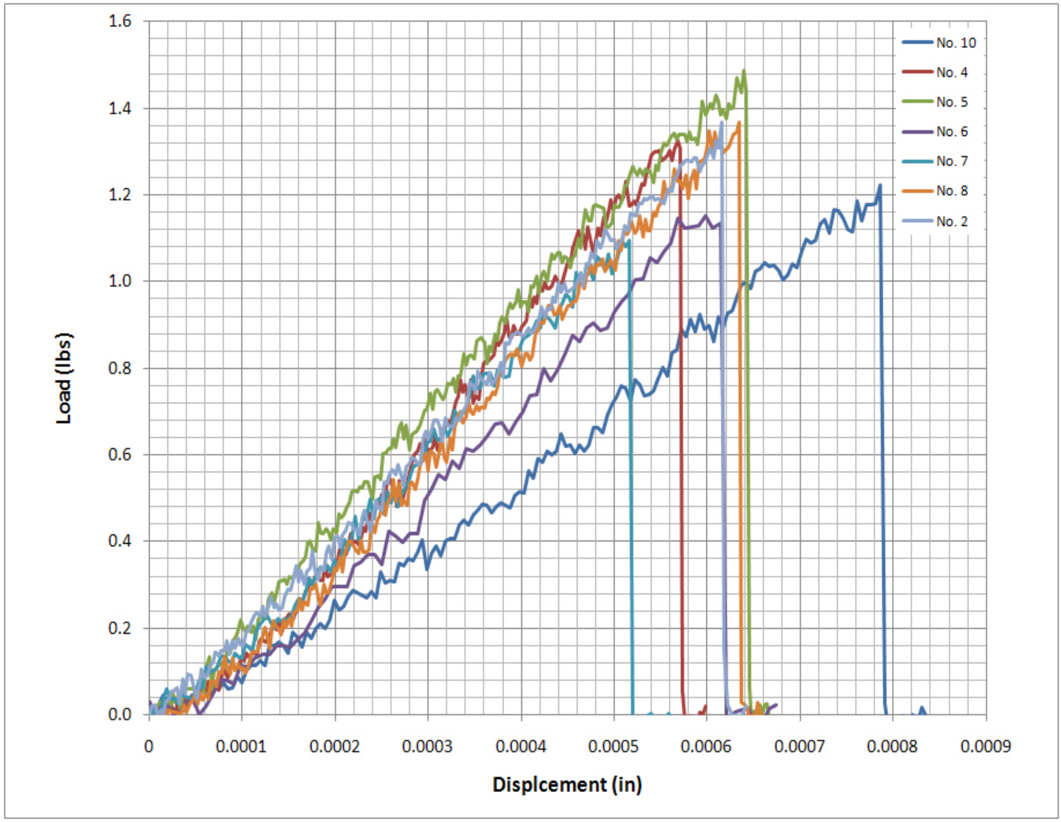
Heat of Adsorption for CO_2



Note: Measured heat of desorption = 27 kJ/mole

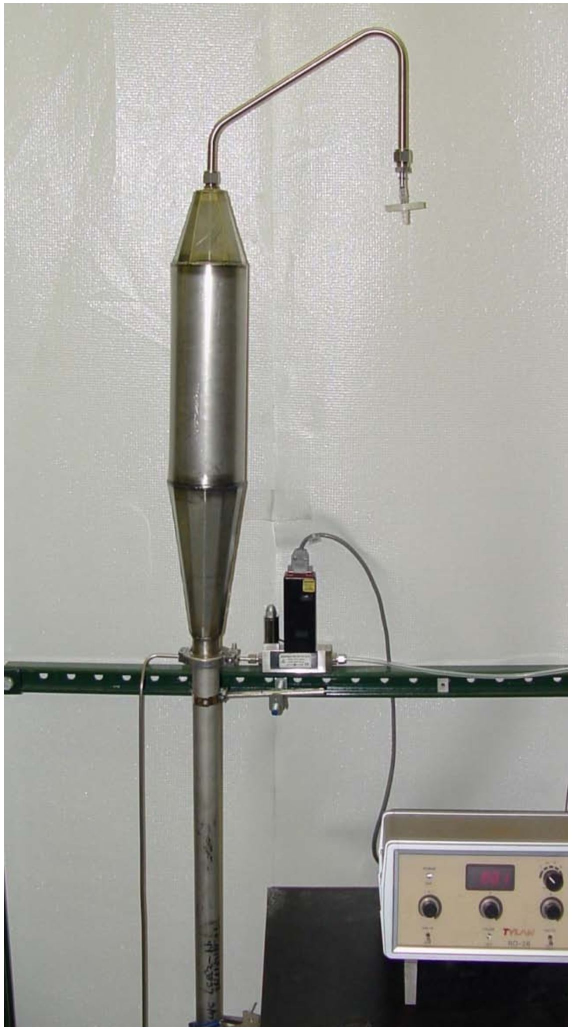
Morphology and Strength

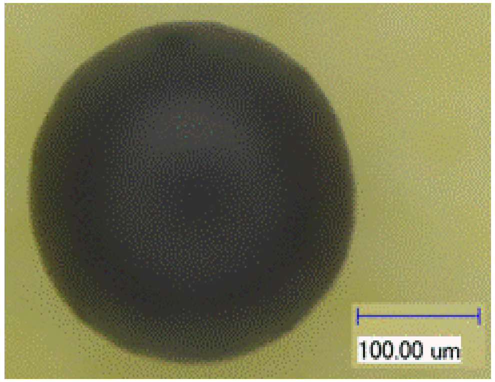




12,000 to 18,000 psi compressive strength

Attrition Resistance





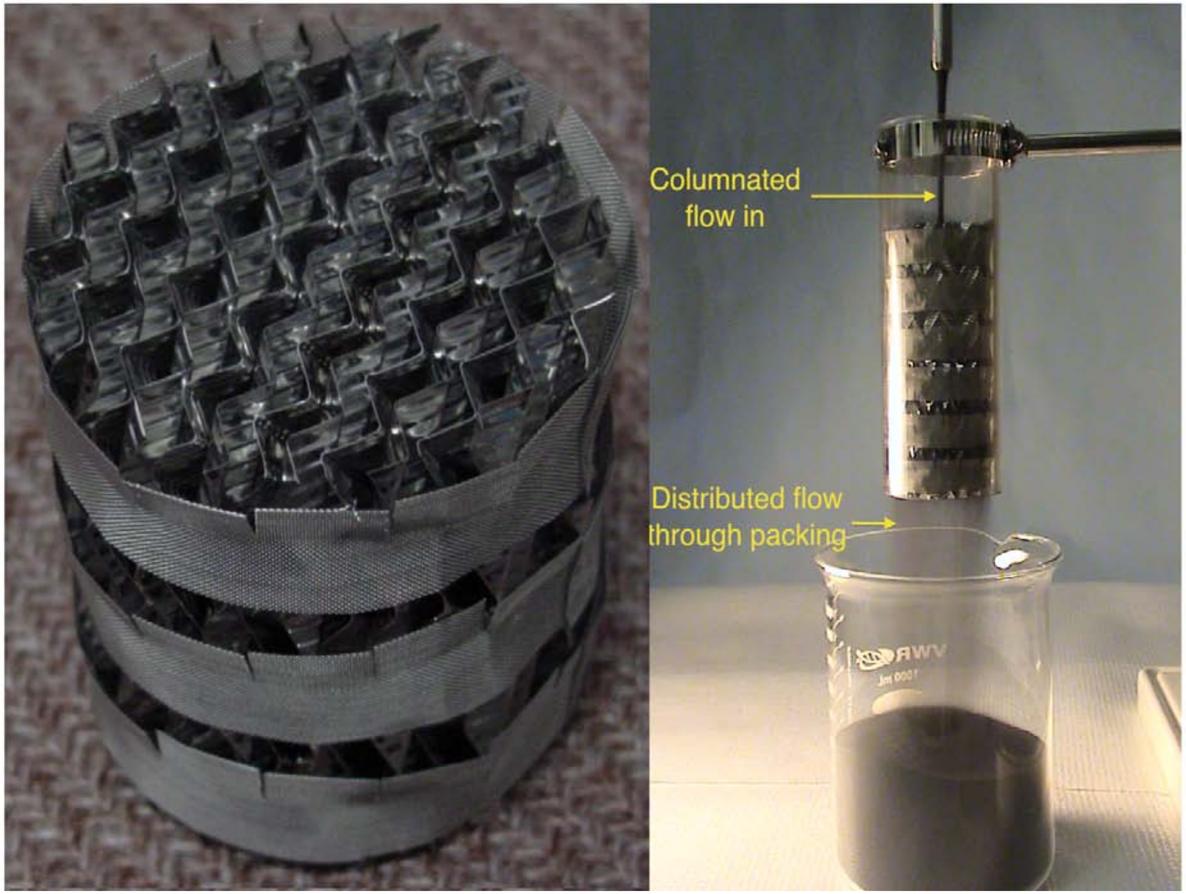
Photograph of a Sorbent Granule

ASTM Test D-5757: Accelerated attrition test using a high velocity gas jet.

Attrition Resistance: Very high;

Weight loss: <0.01%/Hour even at accelerated test conditions

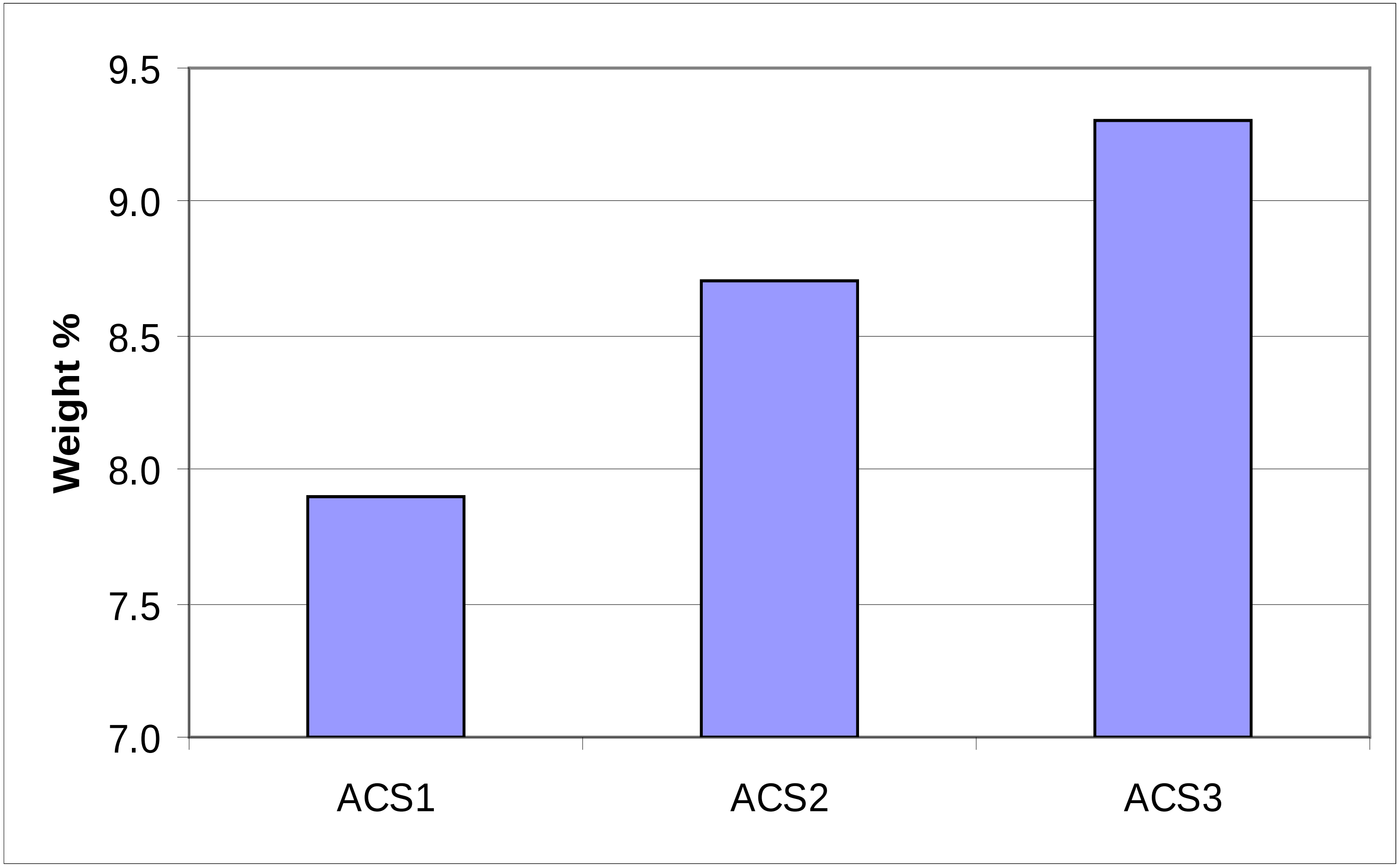
Fluid-like Flow of Sorbents Through a Commercial Structural Packing



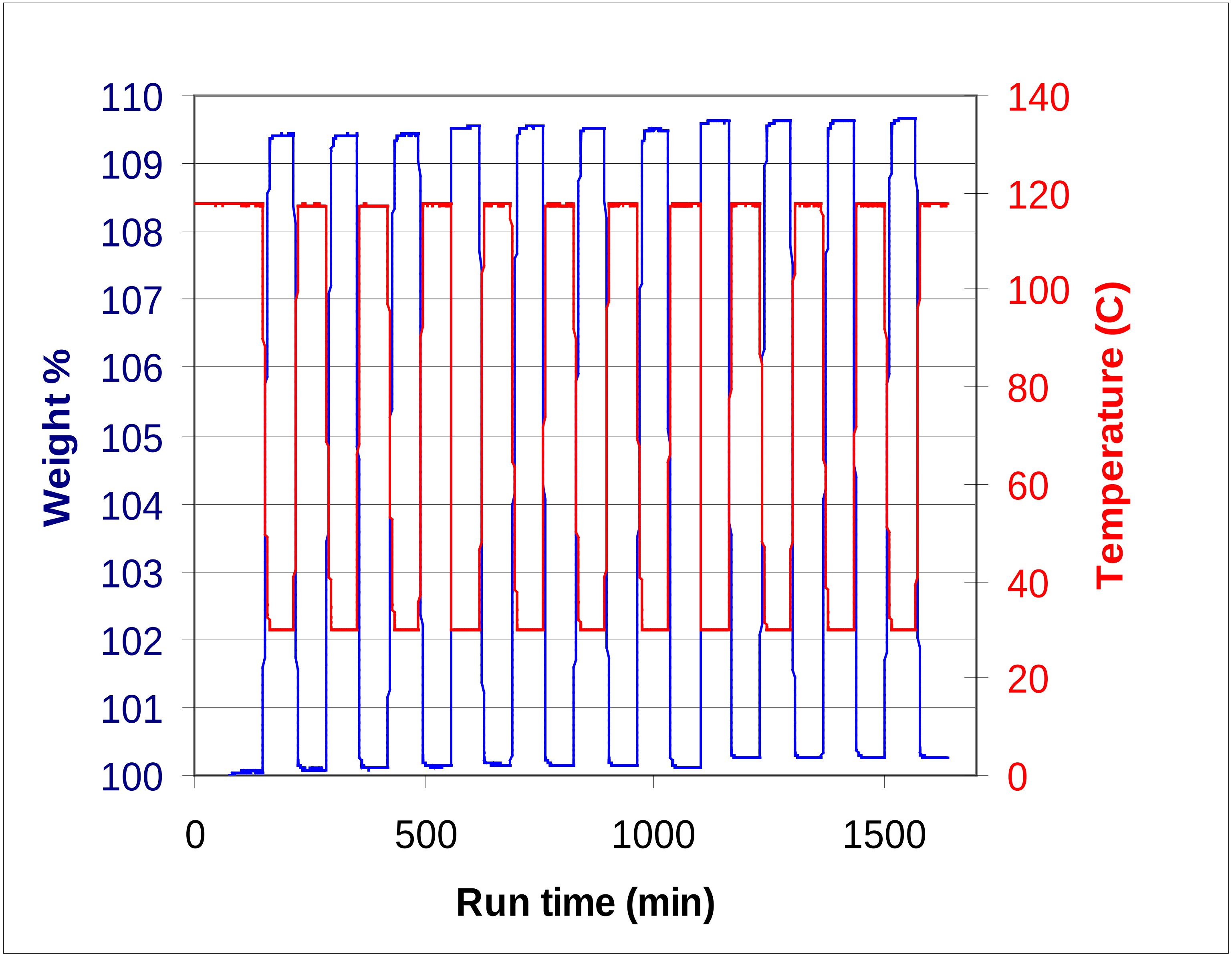
Screening Tests

- Determine the CO_2 capture rate of the current and improved sorbents in a small bench-scale reactor
  - At 20 C using a simulated flue gas containing air and CO_2.
  - Determine the adsorption kinetics and the CO_2 loading
- Heat to 110 C to desorb the CO_2:
  - Determine the desorption kinetics and the CO_2 desorbed.
- Adsorption-regeneration cycles performed.
- No significant changes in the physical and mechanical properties of the aged sorbent.

Differential CO_2 loading Between 30° and 110°C



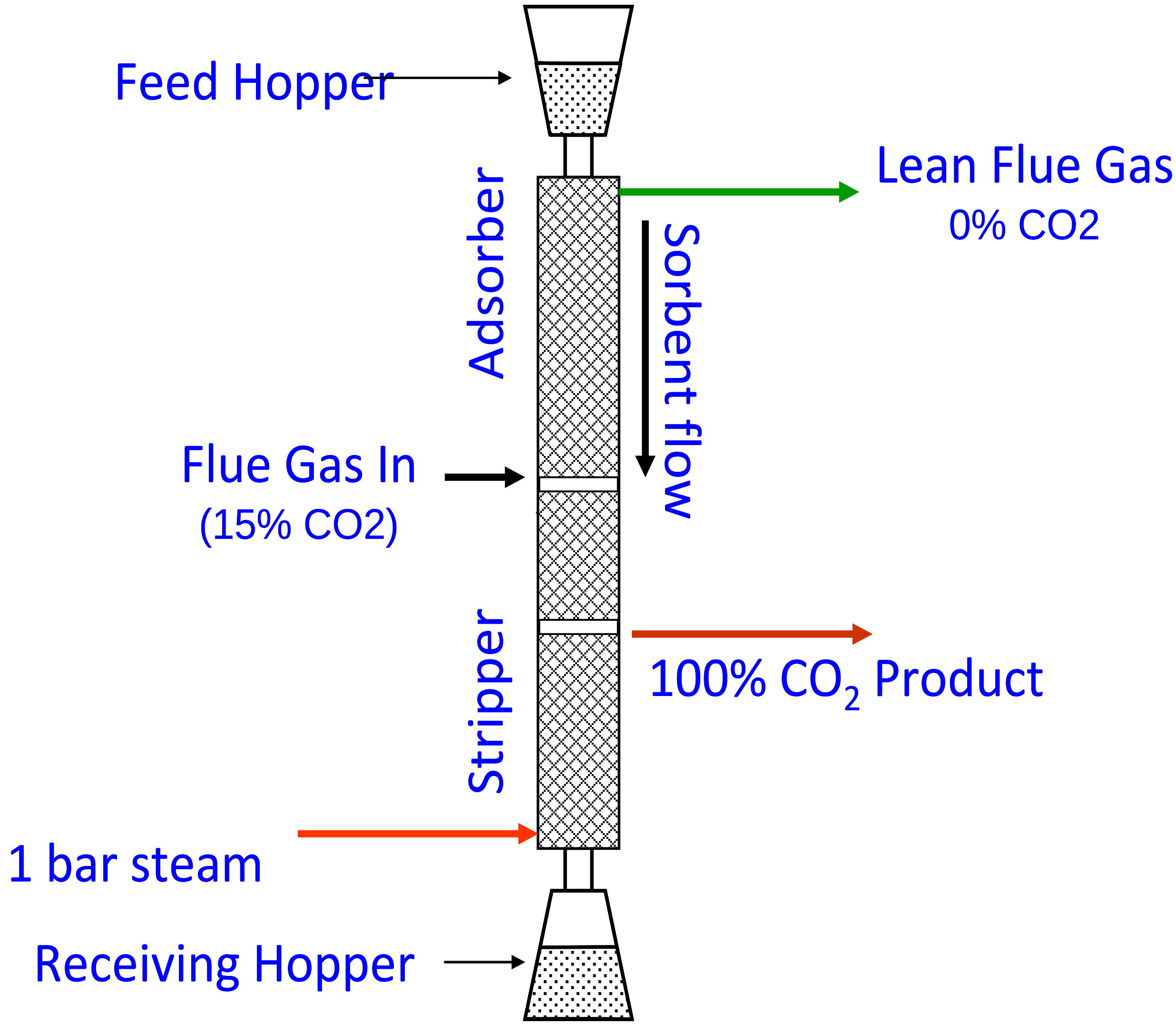
Absorption-Desorption Cycle



Reactor Geometry

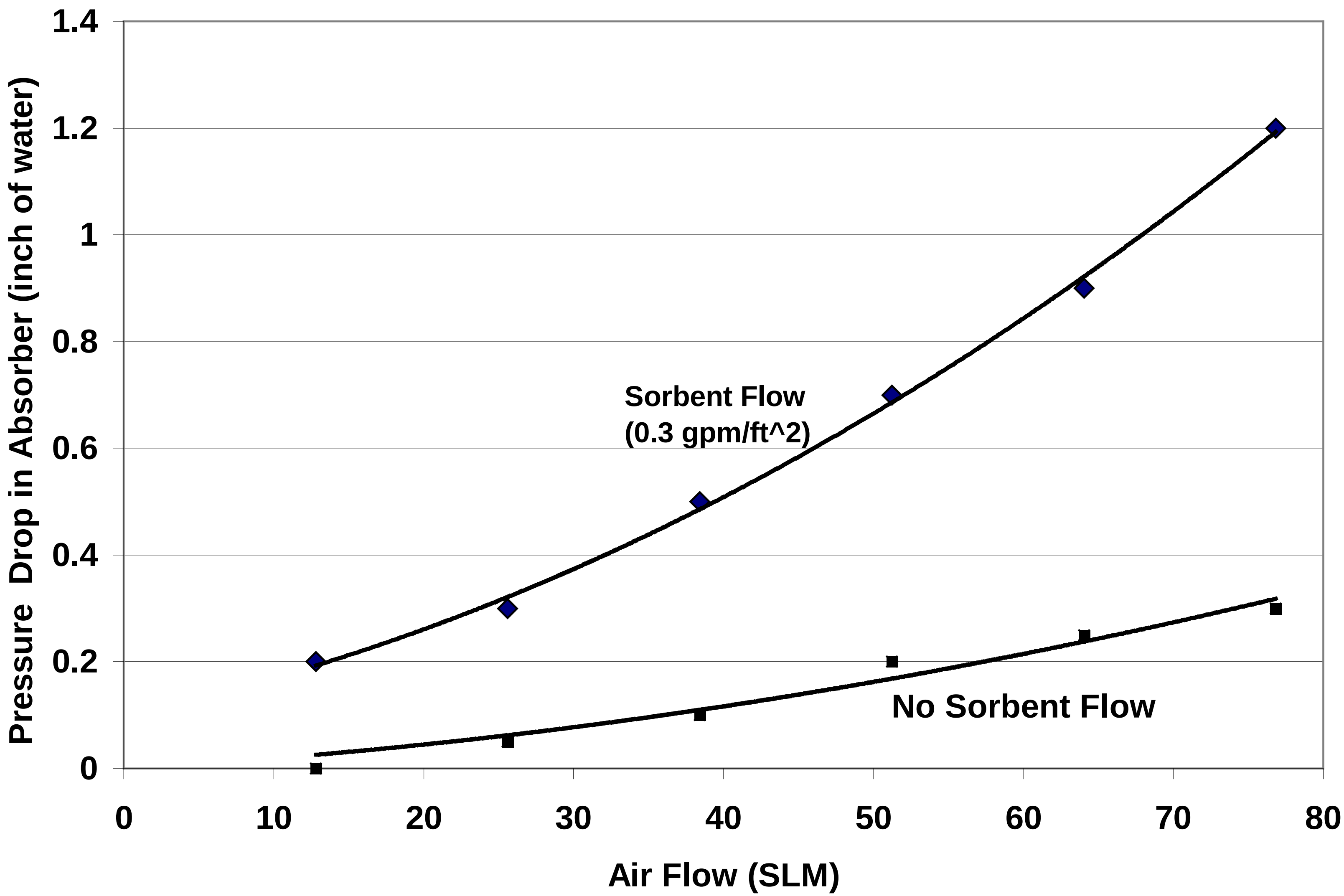
- Reactors for Gas-solid interactions are:
  - Fixed-bed reactors
  - Moving-bed reactors
  - Fluidized- or entrained-bed reactors
- We chose a moving-bed reactor type:
  - Uses a commercial structural packing to distribute the solid
  - Pressure drop for gas flow can be minimum
    - Low operating cost.
  - The sorbent can be cycled rapidly between CO2 capture and release.
    - Low sorbent inventory
  - Reactor volume can be substantially small
    - Low capital cost.

Schematic Diagram of a Novel, Particle Cascading Reactor



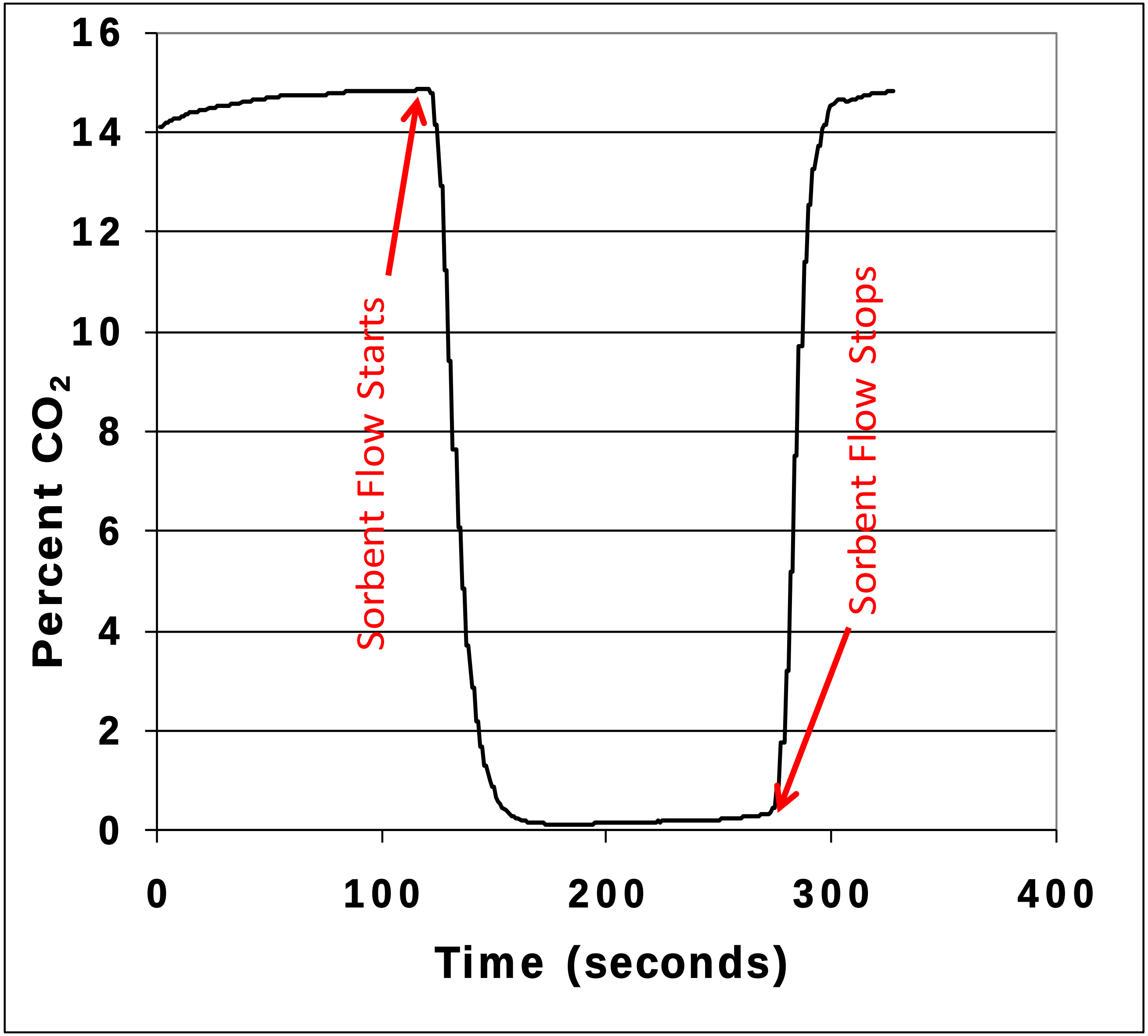
Integrated Absorber-Desorber (Small Bench-Scale Design)

Pressure Drop in the Absorber

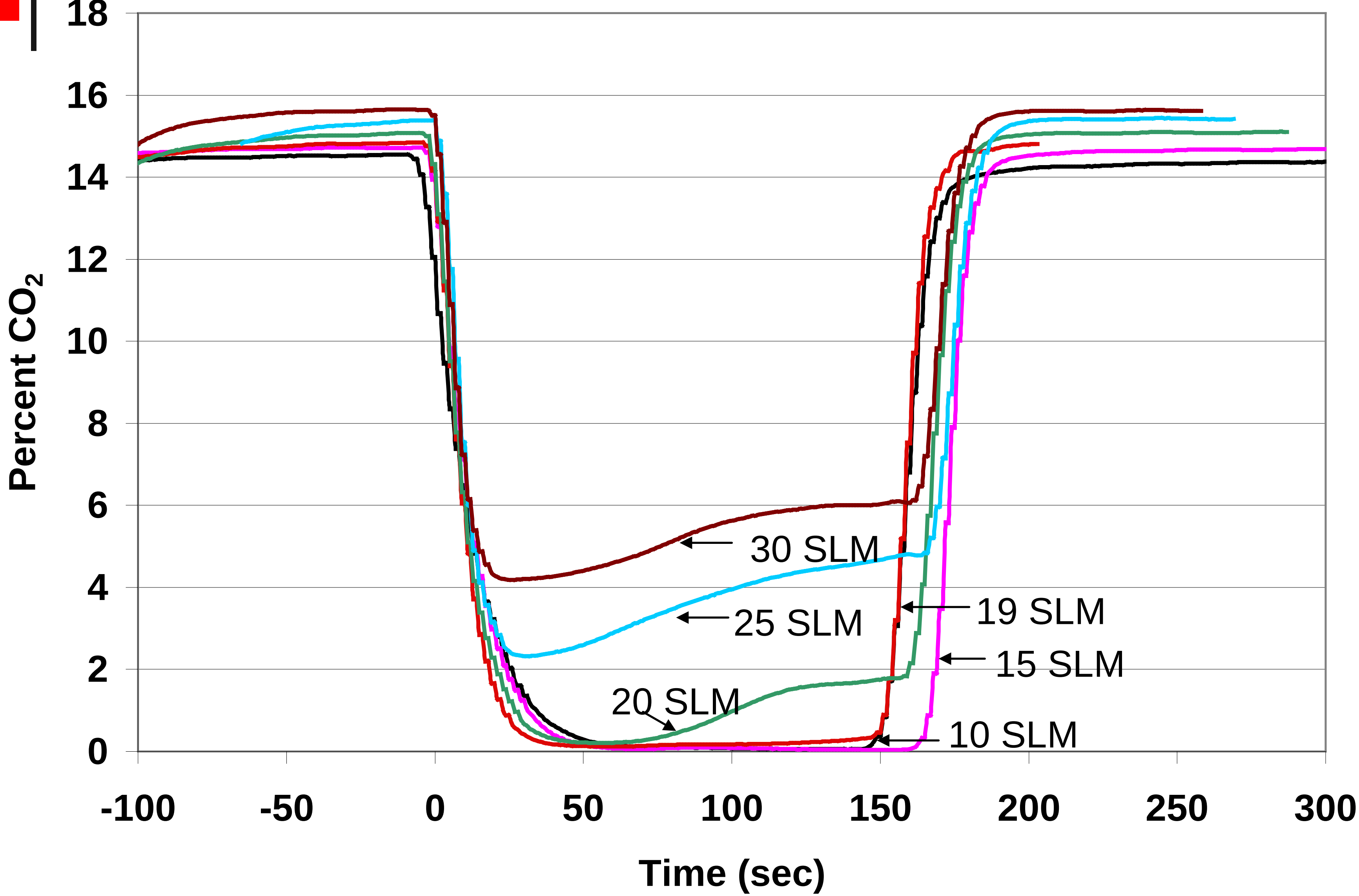


Flow rate of 100 Std.liters/min= 0.91 m/s

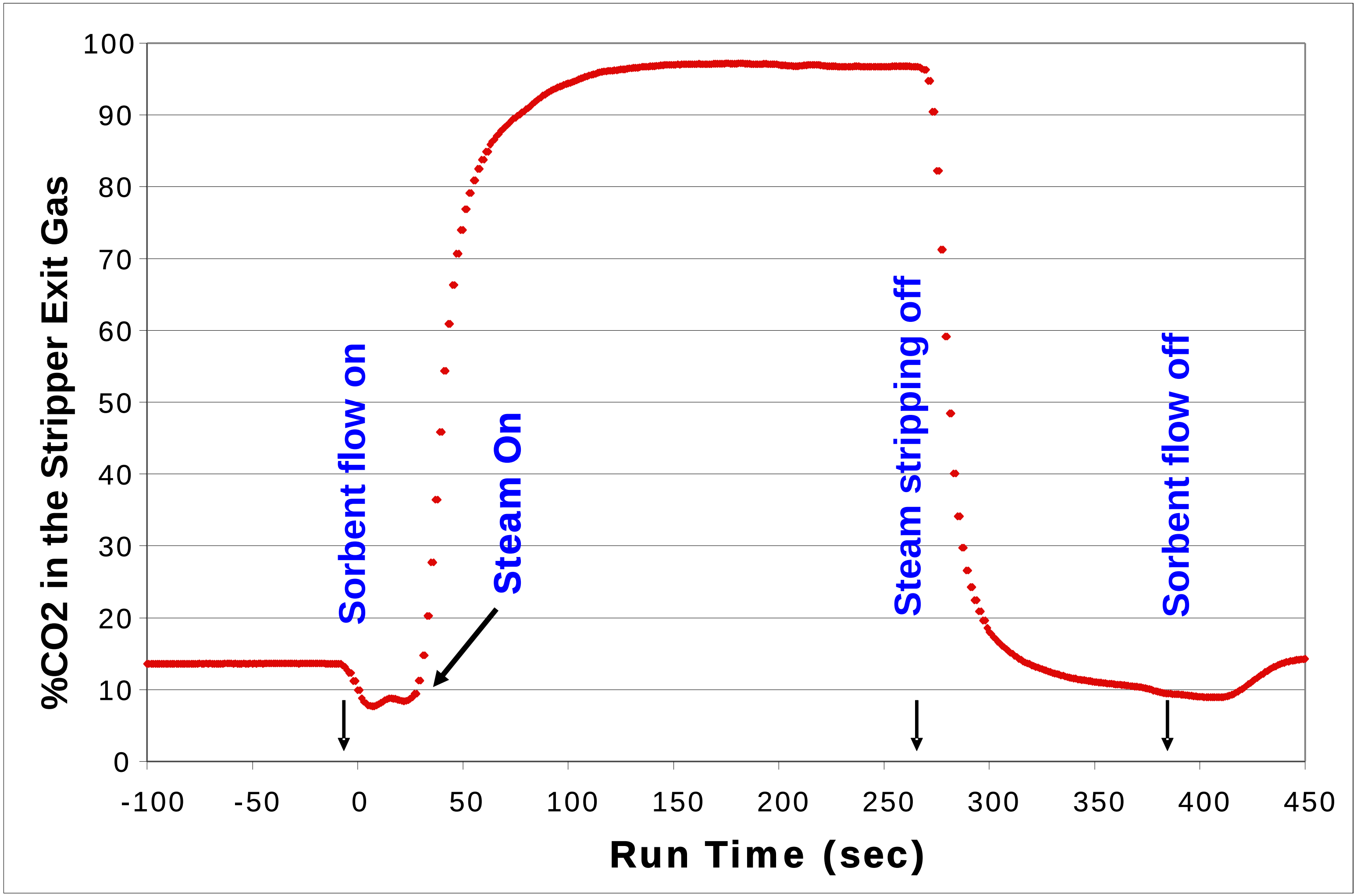
Removal of CO_2 from Air-CO_2 Mixture



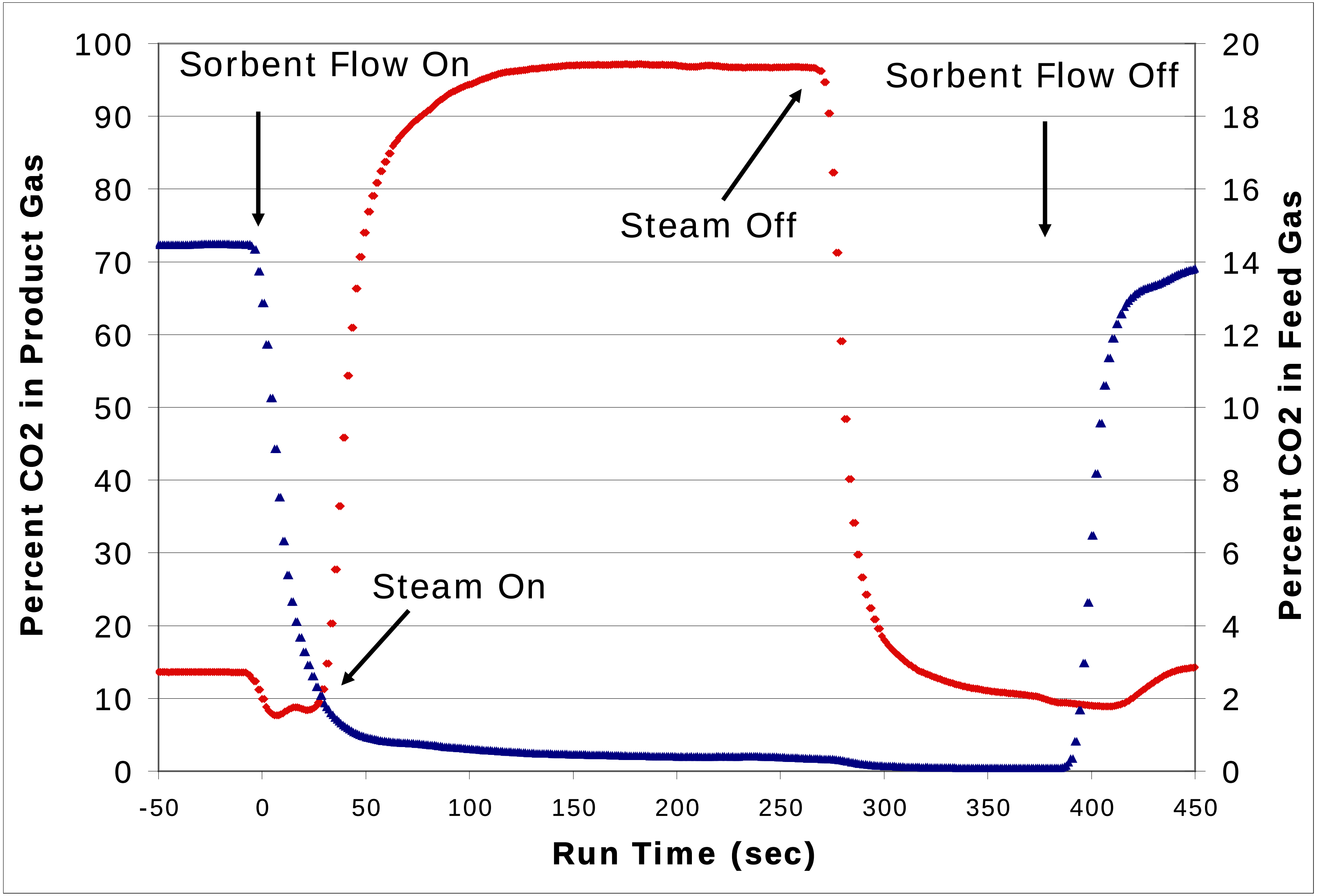
Residual CO_2 concentration as a Function of Gas Flow Rate



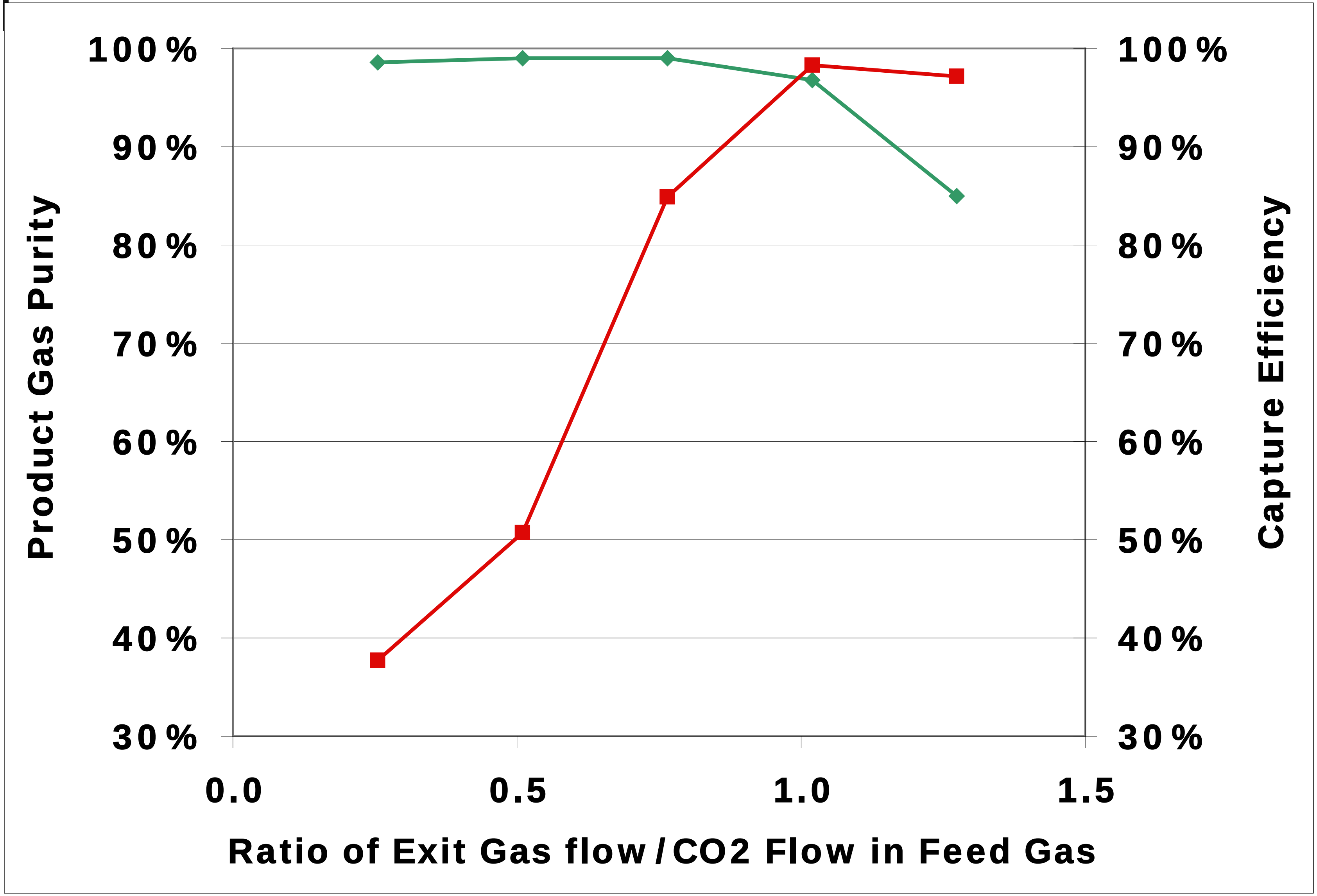
Evolution of CO_2 in the Stripper



Integrated Operation



Capture Efficiency vs Product Gas Purity



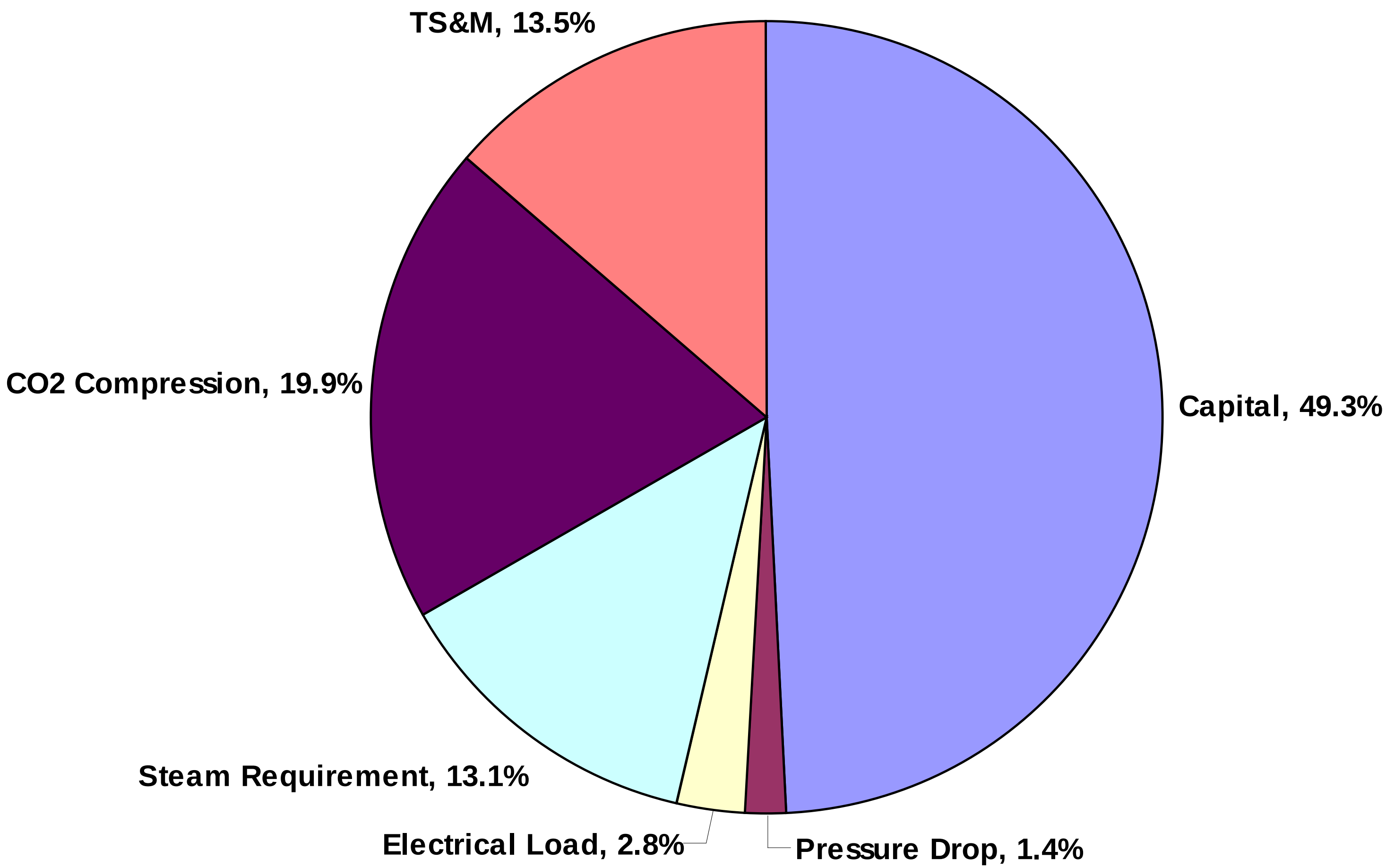
Technical and Economic Analysis

- Steam-Pro model was used to generate the heat, material, and energy flows.
- Use DOE cost model was used to estimate the cost of electricity (COE).
- Base case is an air-fired greenfield supercritical PC plant (700 mW nominal) with no CO_2 capture.
- We compared a similar-size plant using CO_2 capture with carbon sorbent subsystem.

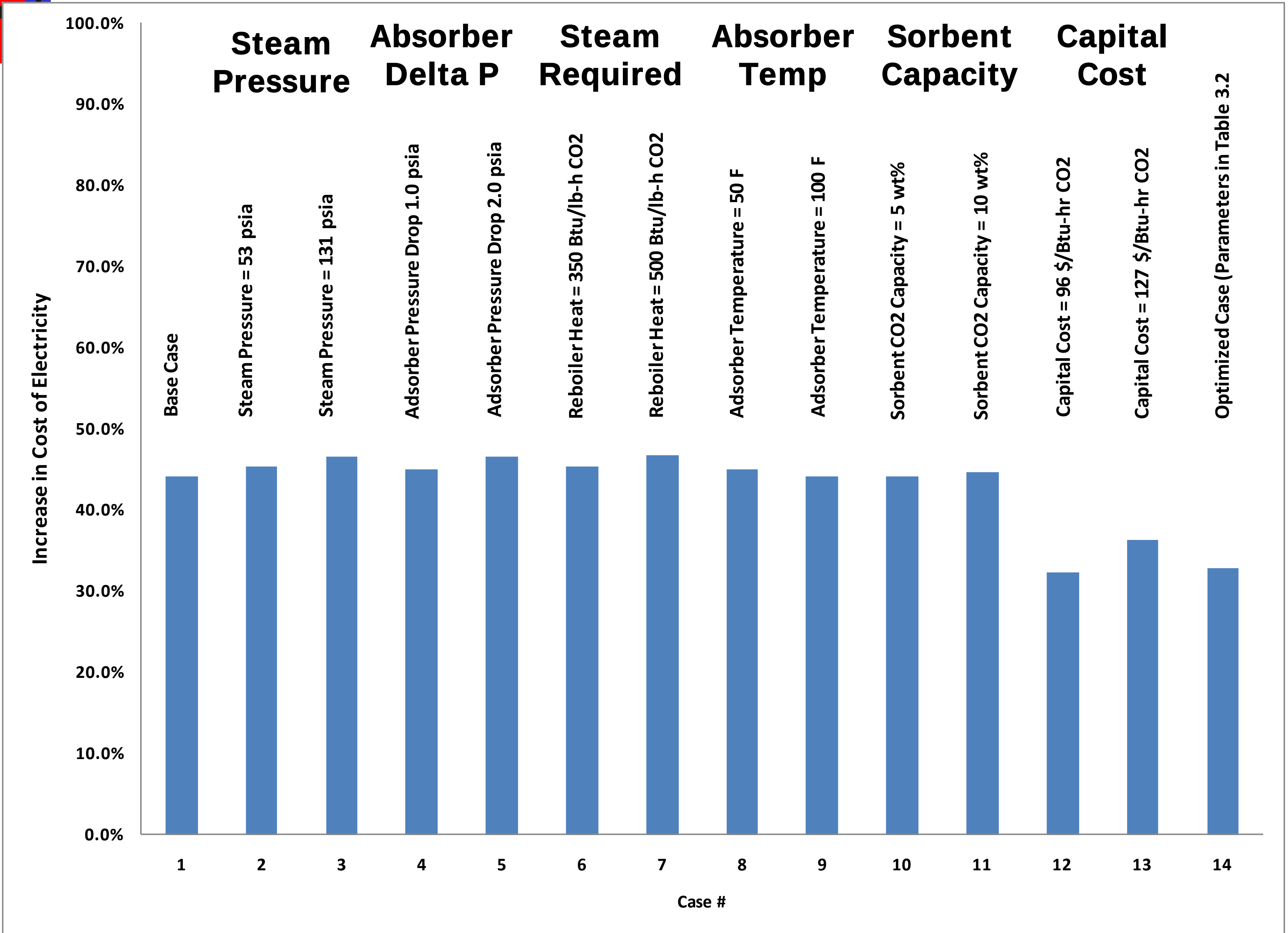
Comparison of CO_2 Capture Costs

	Base Case	Econamine FG+	Carbon Sorbent
CO_2 Capture	**No**	**Yes**	**Yes**
Gross Power Output (kW)	581,034	679,911	640,421
Auxiliary Power Requirement (kW)	31,016	129,485	90,246
Net Power Output (kW)	**550,018**	**550,426**	**550,175**
Net Plant HHV Efficiency (%)	**38.9%**	**27.1%**	**35.1%**
Net Plant HHV Heat Rate (Btu/kW-hr)	8,859	12,590	9,717
Coal Flowrate (lb/hr)	414,000	594,000	458,280
CO_2 Emissions (lb/MWh)	1,790	252	194
Total Plant Cost ($ x 1000)	872,118	1,586,765	1,224,213
Total Plant Cost ($/kW)	1,586	2,883	2,225
LCOE (¢/kWh)	**6.40**	**11.58**	**9.23**
Increase in COE (%)	**0.0%**	**80.9%**	**44.2%**

Break-Down of the CO_2 Capture Cost Using Advanced Carbon Sorbent (Initial)



Increase in COE for Different Cases



Achievements

- Determined several physical and chemical properties of the advanced carbon sorbent in the context of flue gas CO_2 capture.
- Demonstrated an unique sorbent for CO_2 capture
  - Achieved ~99% CO_2 capture from air-CO_2 gas mixture
  - Achieved >98% pure CO_2 during regeneration
  - Capable of rapid adsorption and regeneration
  - Low heat requirements for regeneration
  - Fluid-like flow properties
  - High attrition resistance
- Developed an unique reactor system
  - Integrated absorber-desorber geometry
  - Minimize solids handling
  - Minimize heat exchanger requirements

Future Plans

- Plans for next year:
  - 1000-cycle test under integrated adsorption-desorption conditions
  - Evaluation of the technical merits and increase in cost of electricity for CO_2 capture using the novel carbon sorbents
- Plans for the next phase:
  - Field testing of the process using a flue gas from an operating PC-fired boiler.

Team

- SRI International
  - Dr. Gopala Krishnan – Associate Director (MRL) and PI
  - Dr. Angel Sanjurjo – Materials Research Laboratory Director and Project Supervisor
  - Dr. Marc Hornbostel, Senior Materials Scientist
- ATMI Inc.
  - Sorbent developer, Industry perspective
  - Dr. Joshua B. Sweeney, PhD; Director, Business Development
  - Dr. Lawrence H. Dubois Ph.D; Senior Vice President and Chief Technology Officer
  - Dr. Donald Carruthers; Senior Research Scientist
- DOE-NETL
  - Mr. Andrew O'Palko, Project Manager