Development Novel Carbon Sorbents for Carbon Dioxide Capture

Annual NETL CO_2 Capture Technology for Existing Plants R&D Meeting

March 24 -26, 2009 in Pittsburgh, PA.

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Profile of SRI International

SRI is one of the world's largest independent R&D organizations

- Founded 1946 as the Stanford Research Institute in conjunction with Stanford University
- Independent, not-for-profit scientific research institute with for-profit spin-offs and subsidiaries (Sarnoff Corporation and SRI Consulting)
- Creating and delivering innovative science and technology solutions for governments and businesses worldwide.

- Annual combined revenues exceed $400 million:
- 1,300 employees, 700 with advanced degrees
- Headquarters in Menlo Park, CA, offices in Washington, D.C. and throughout the U.S.

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Project Overview

- Partners:
  - SRI International, Menlo Park, CA
  - ATMI, Inc., Danbury, CT
- 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.
- Rapid adsorption and desorption rates (no solid state diffusion limit).
- Minimize thermal energy requirements
  - Relatively low desorption temperature.
  - Low heat of desorption.
- Potential to desorb in 1 atm CO_2.

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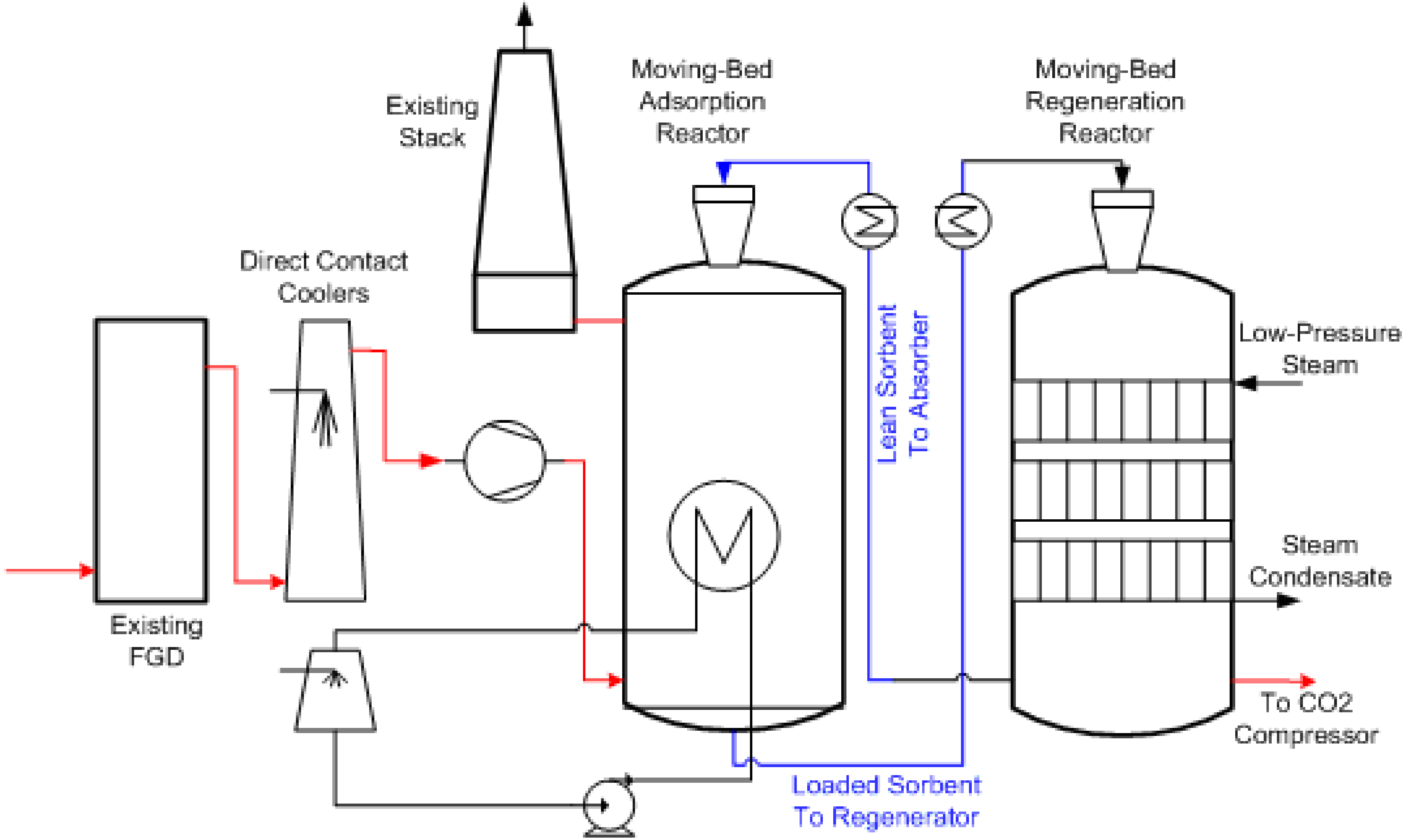
Advantages of the Carbon Sorbents

- Low cost and stable sorbent: In the operating range of 20° to 100°C, the carbon sorbent is very stable.
- High capacity of CO_2 loading (0.1 to 0.2 kg of CO_2 per kg of sorbent)
- 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.

Physical Properties of the Current 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/l)
- Unusually tough for a high surface area porous solid

Schematic Process Description



Technical Challenges

- Competitive adsorption of moisture and other flue gas components (SOx, and NOx).
- Adsorption temperature
  - Low temperature promotes adsorption
    - Removal of heat during adsorption
- Reactor configuration
  - Fixed-, moving-, or fluid-bed reactor
- Heat exchange between loaded (cold) and regenerated (hot) sorbents.

Project Objectives

- Validate the performance of novel carbon sorbents for CO_2 capture on a bench-scale system in 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

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.

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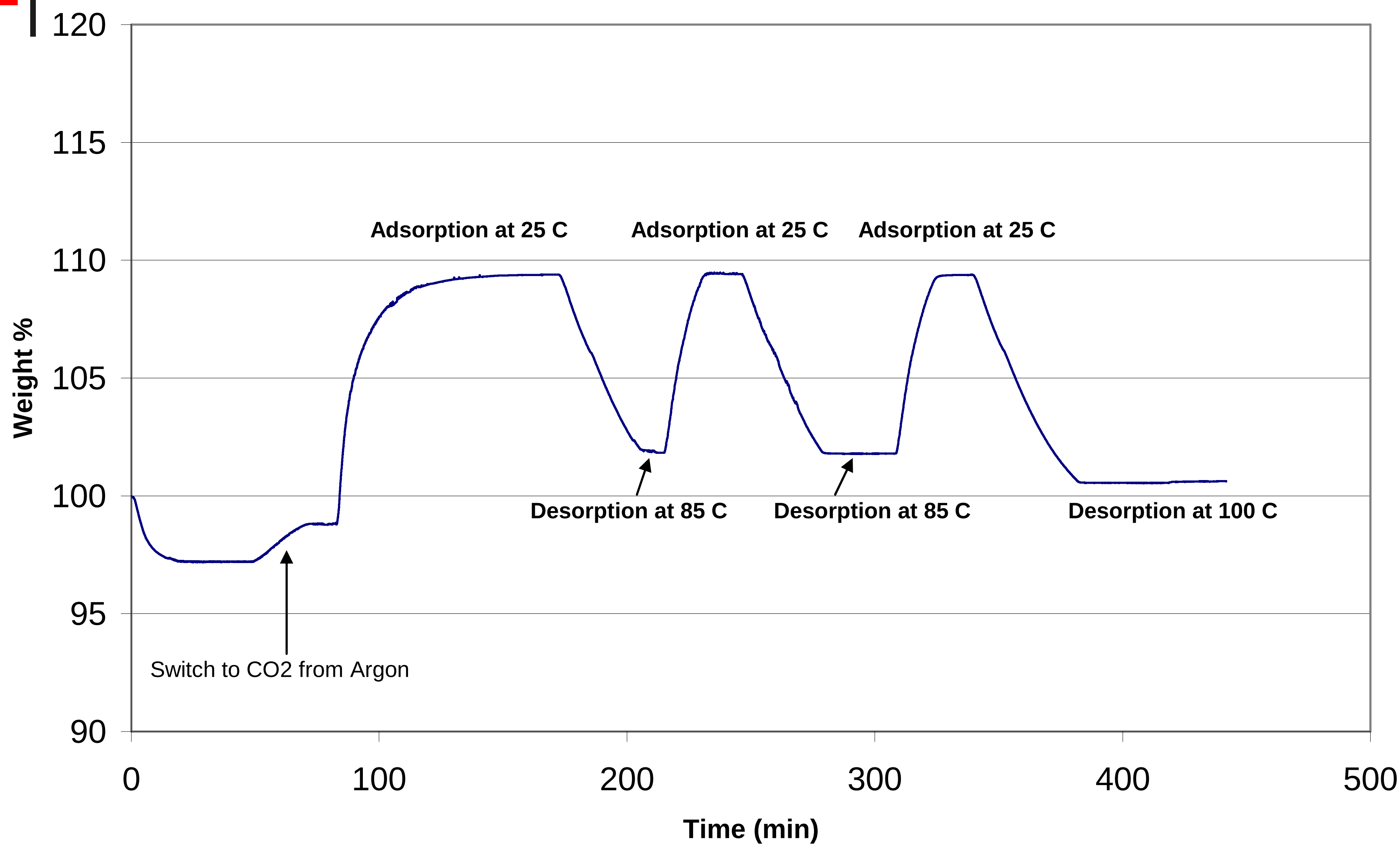
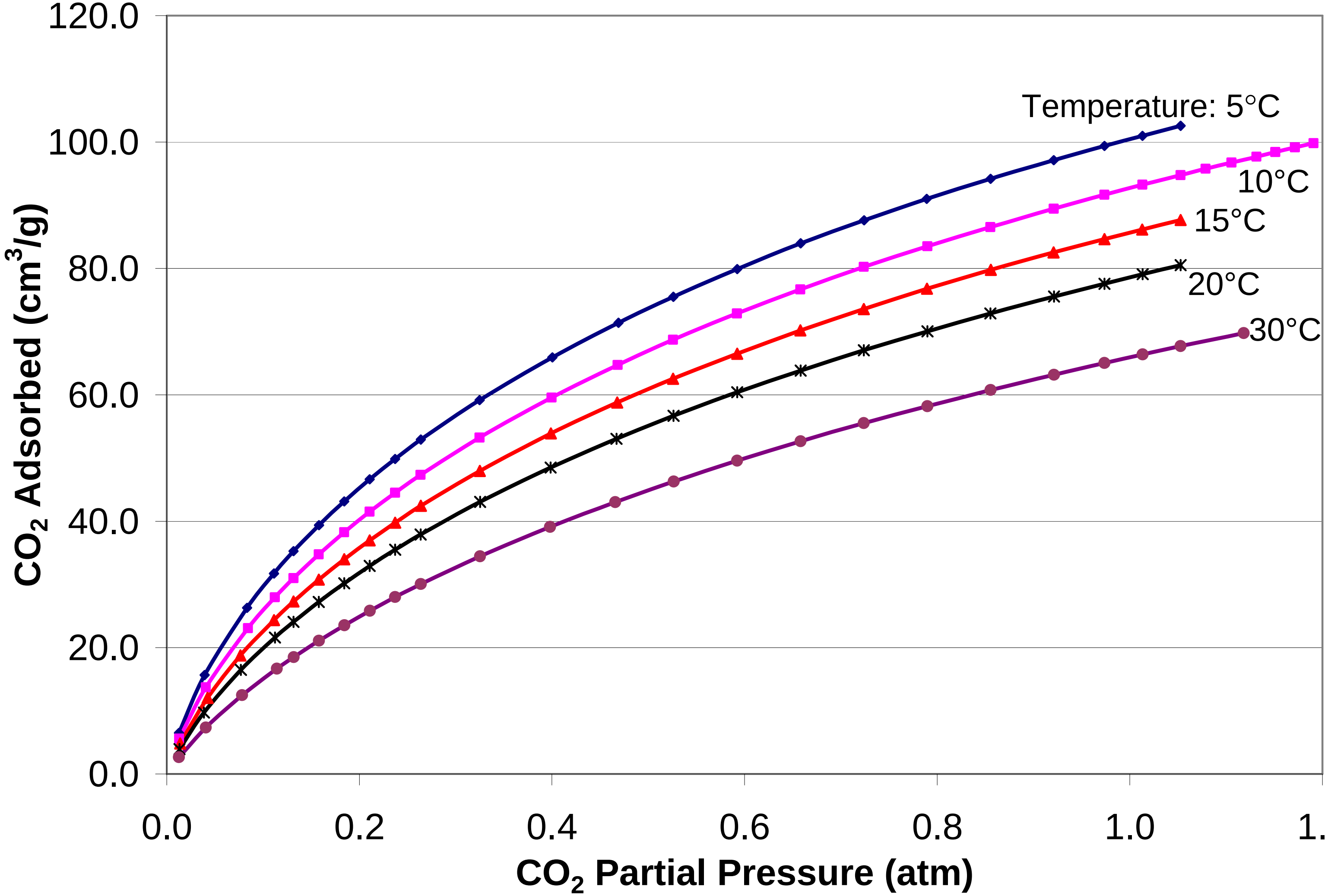
Relevant Properties of the Sorbent

- Surface area, 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 moving bed reactors

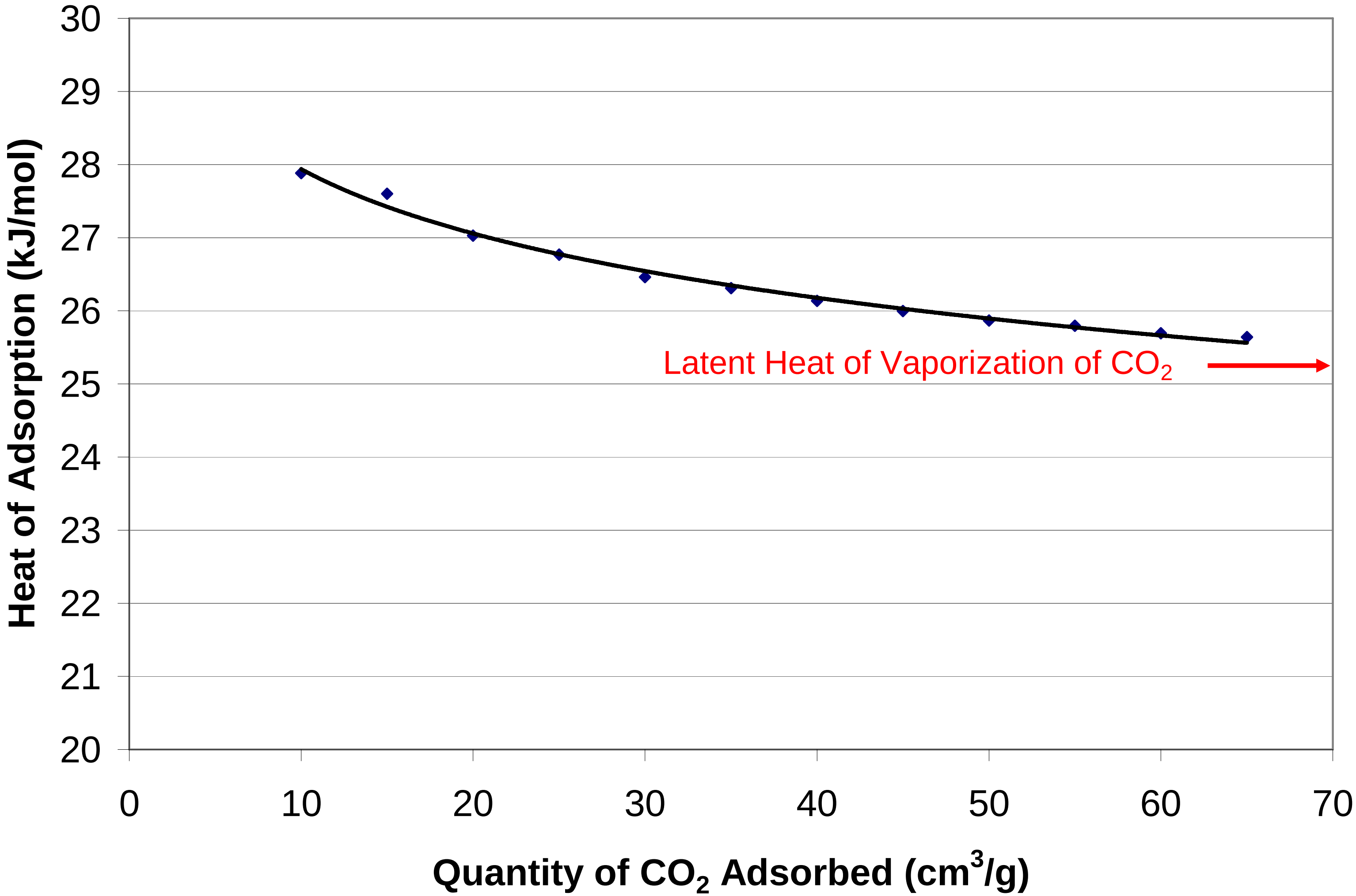
Cyclic Adsorption (30°C) and Regeneration (100°C)



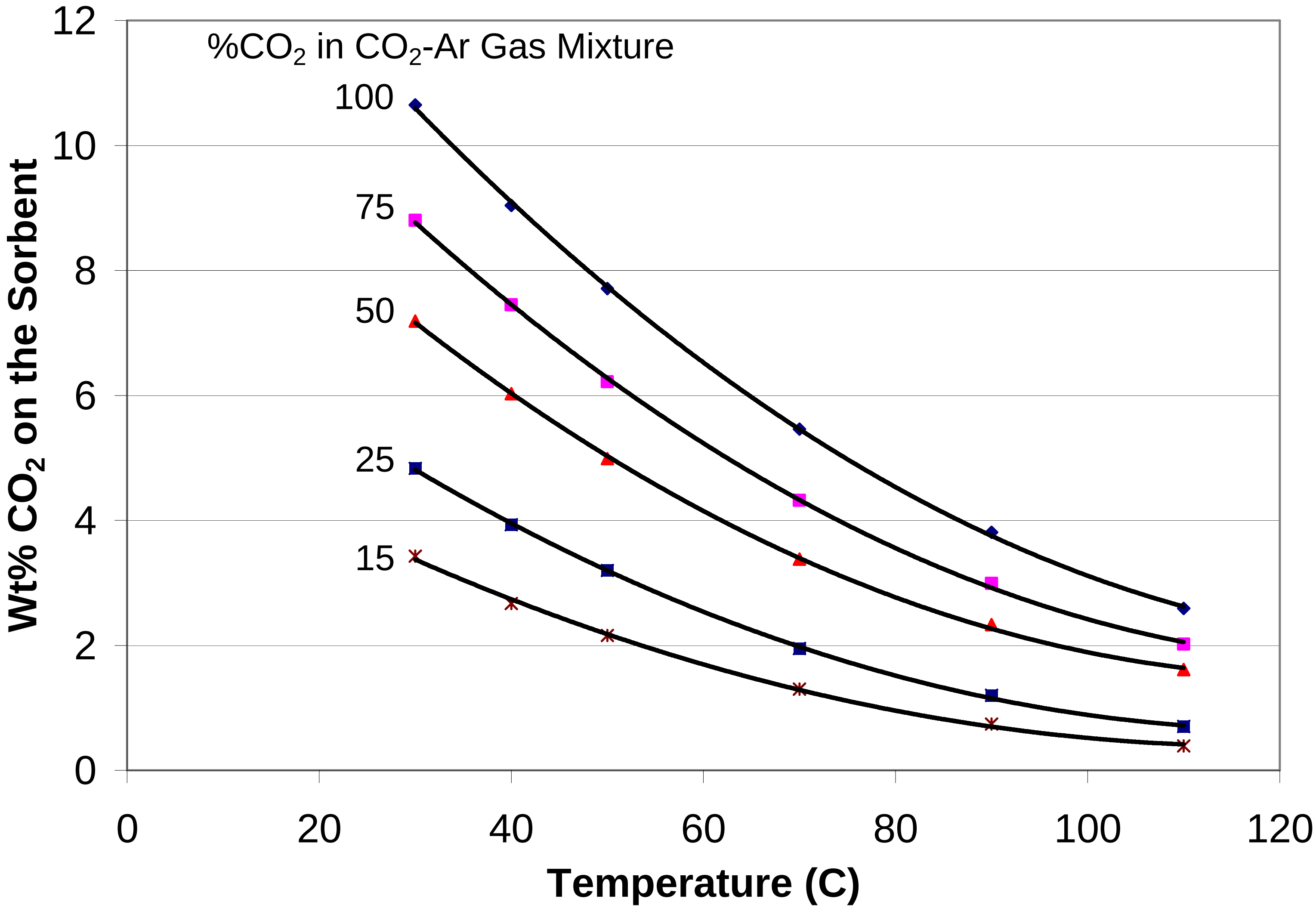
CO_2 Adsorption Isotherms



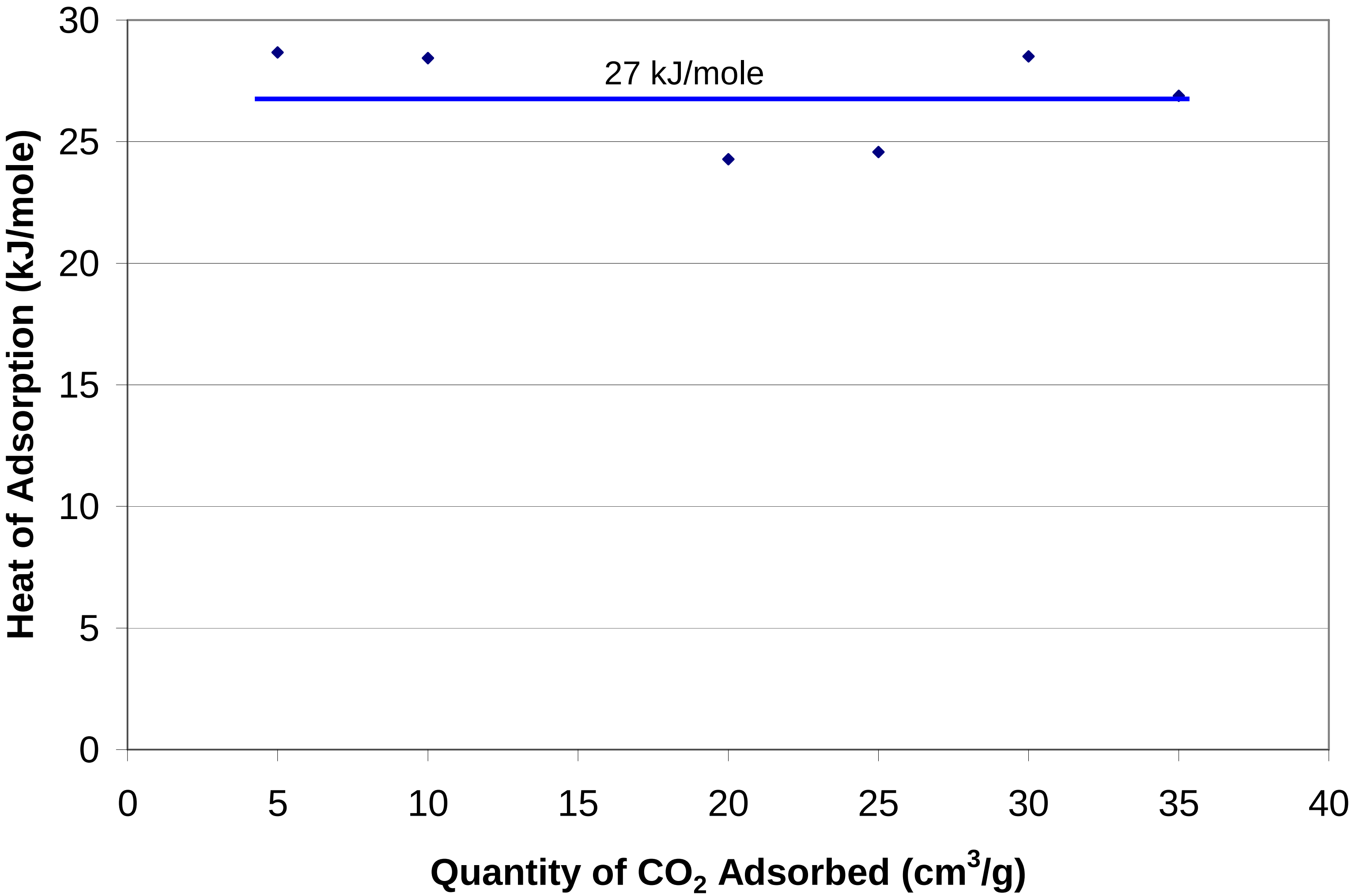
Heat of Adsorption for CO_2



Desorption of CO_2



Heat of Desorption for CO_2



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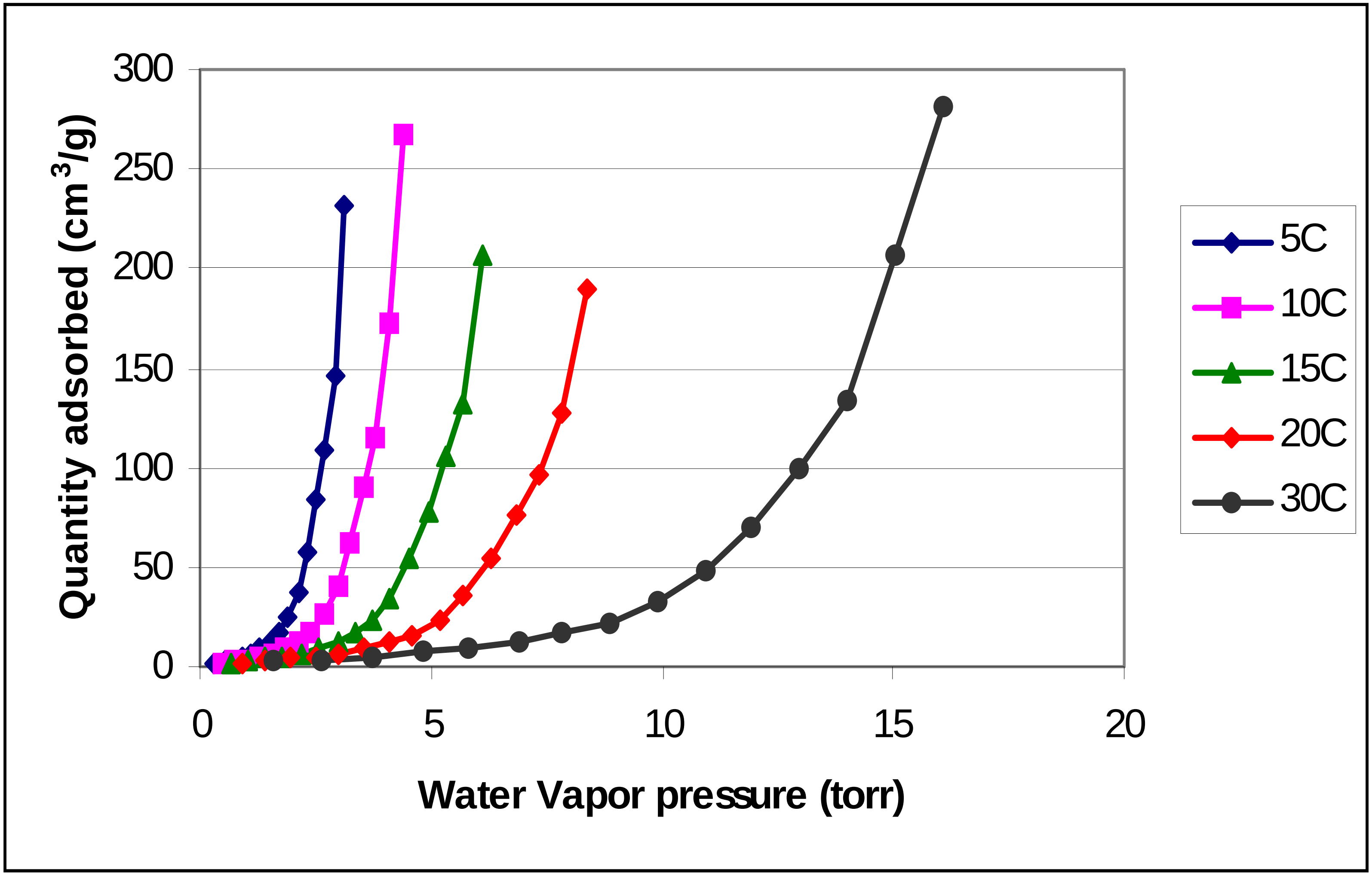
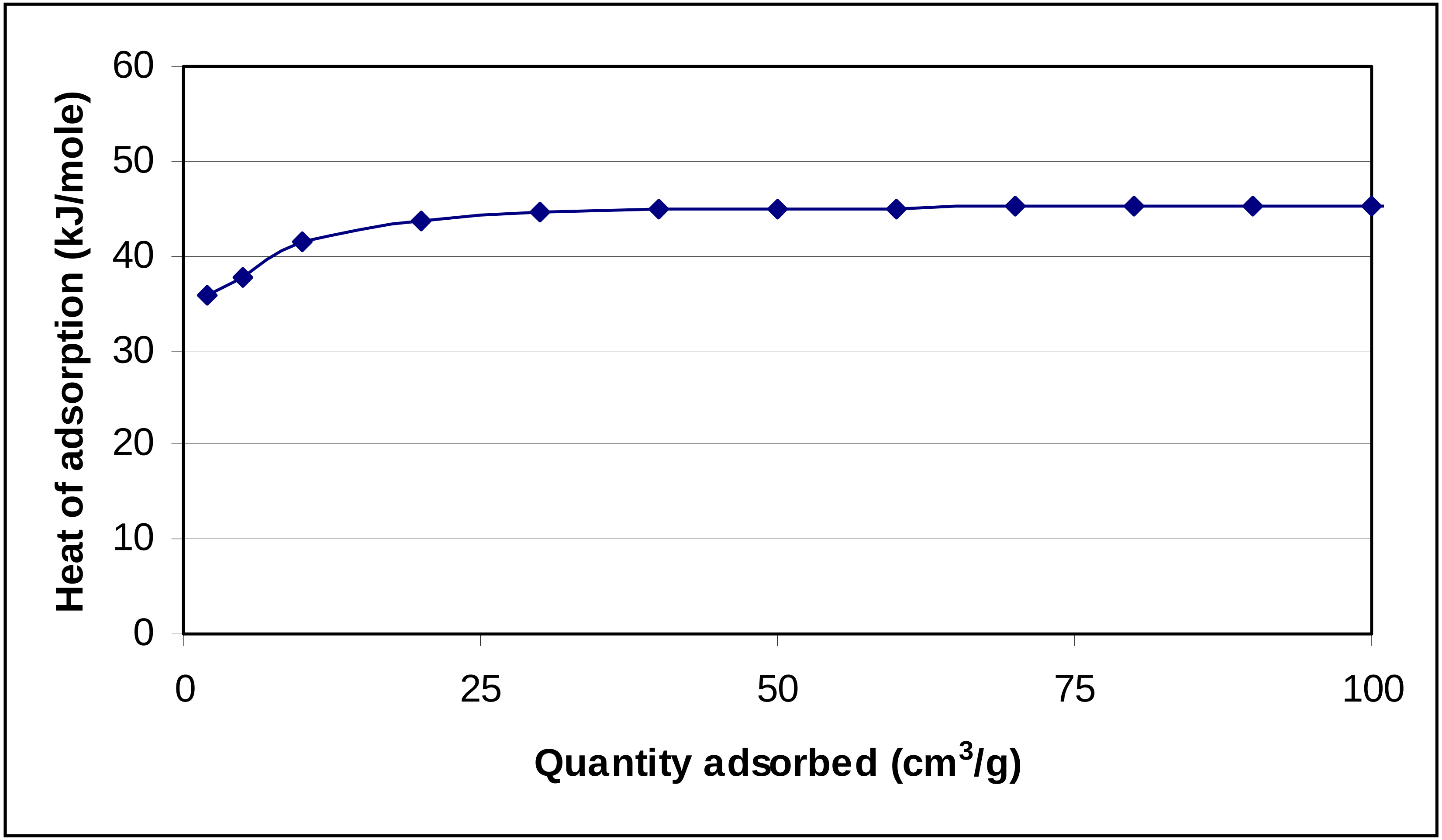
Water Vapor Adsorption Isotherms

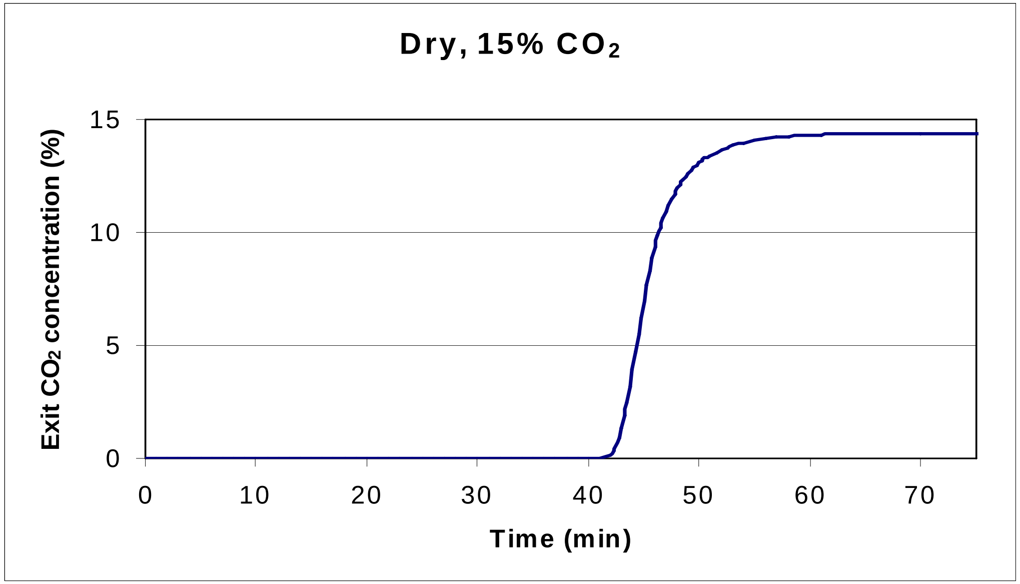


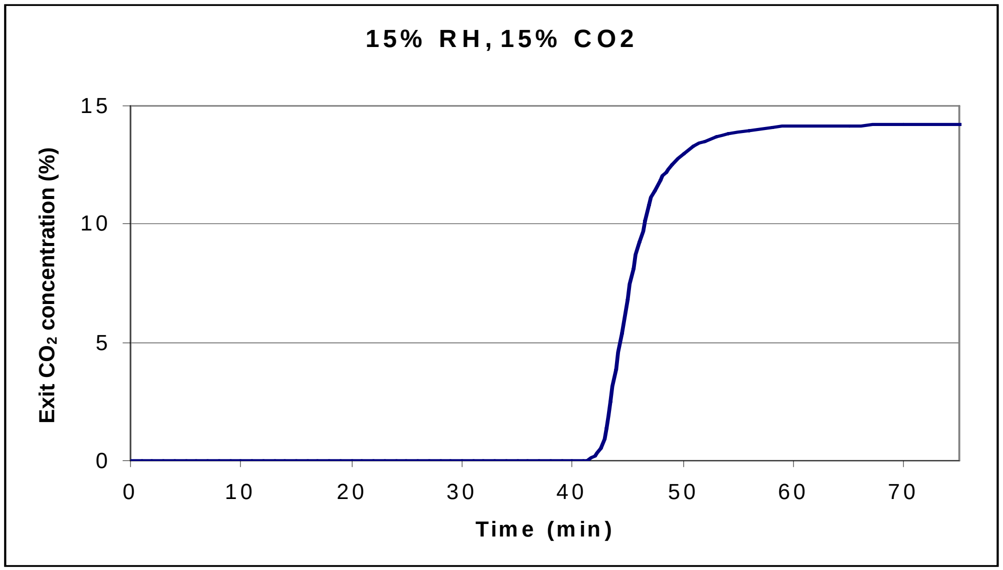
Water Vapor Heat of Adsorption



Fixed Bed Break-through Experiment

- Better than 99% capture until saturation
- No effect of moisture on CO_2 capture
- Need to examine higer moisture content





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
- Rapidly heat to 120°C to desorb the CO_2:
  - Determine the desorption kinetics and the CO_2 desorbed.
- Ten adsorption-regeneration cycles with selected sorbents
- Determine the changes in the physical and mechanical properties of the aged sorbent.

Future Parametric Testing

- Bench-scale fixed-bed reactor of ~3-in diameter
- Absorber parametric testing
  - Gas velocity = 2 to 6 ft/s;
  - Temperature =5° to 30°C;
  - CO_2 inlet level = 5 to 15% v/v;
  - Sorbent pellet size and geometry;
  - Presence of SO_2 and NO_X in concentrations typical of a flue gas stream.
- Regenerator parametric testing
  - Temperature (75° to 100°C);
  - Direct and indirect heating.
- Cyclic testing:
  - Selected sorbents will be tested for 100 cycles

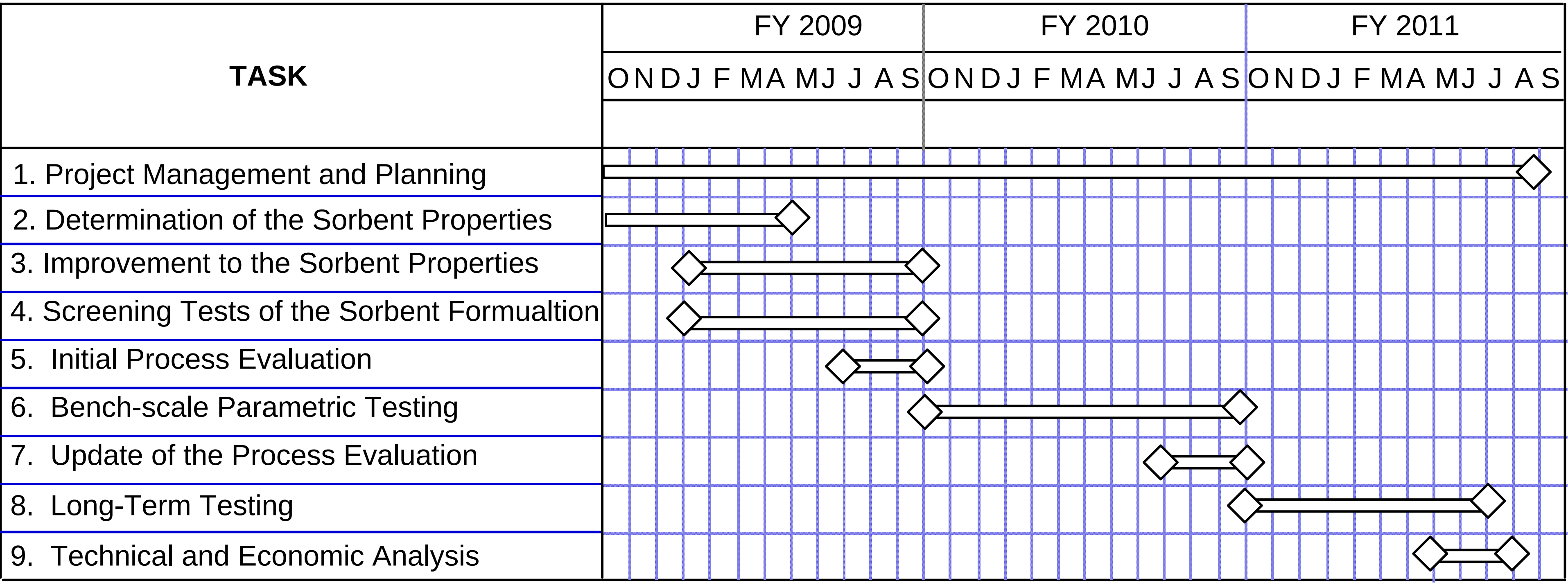
Long-Term Tests

- 1000-cycle test of the most superior formulation (determined in the bench scale parametric testing)
- Process conditions for CO_2 capture using a simulated flue gas containing major and minor components.

Technical and Economic Analysis

- Aspen modeling will be used to generate the equipment sizing and heat and material flows.
- Use DOE cost models
- Base case will be an air-fired greenfield supercritical PC plant (700 mW nominal) with no CO_2 capture.
- Compare a similar-size plant using CO_2 capture with carbon sorbent subsystem.

Project Schedule



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Summary

- A promising and exciting start.
- Bench-scale system for screening test is ready and available.
- Sorbent property measurements are underway.
- Potentially a significant reduction in the cost of CO_2 capture.

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Team

- SRI International
  - Dr. Gopala Krishnan – Associate Director (MRL) and PI
  - Dr. Angel Sanjurjo – Materials Research Laboratory Director and Project Supervisor
  - Dr. Indira Jayaweera – Senior Chemist
- 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
  - Andrew O'Palko