Development Novel Carbon Sorbents for Carbon Dioxide Capture

2013 NETL CO_2 Capture Technology Meeting

July 8-11, 2013, Pittsburgh, PA.

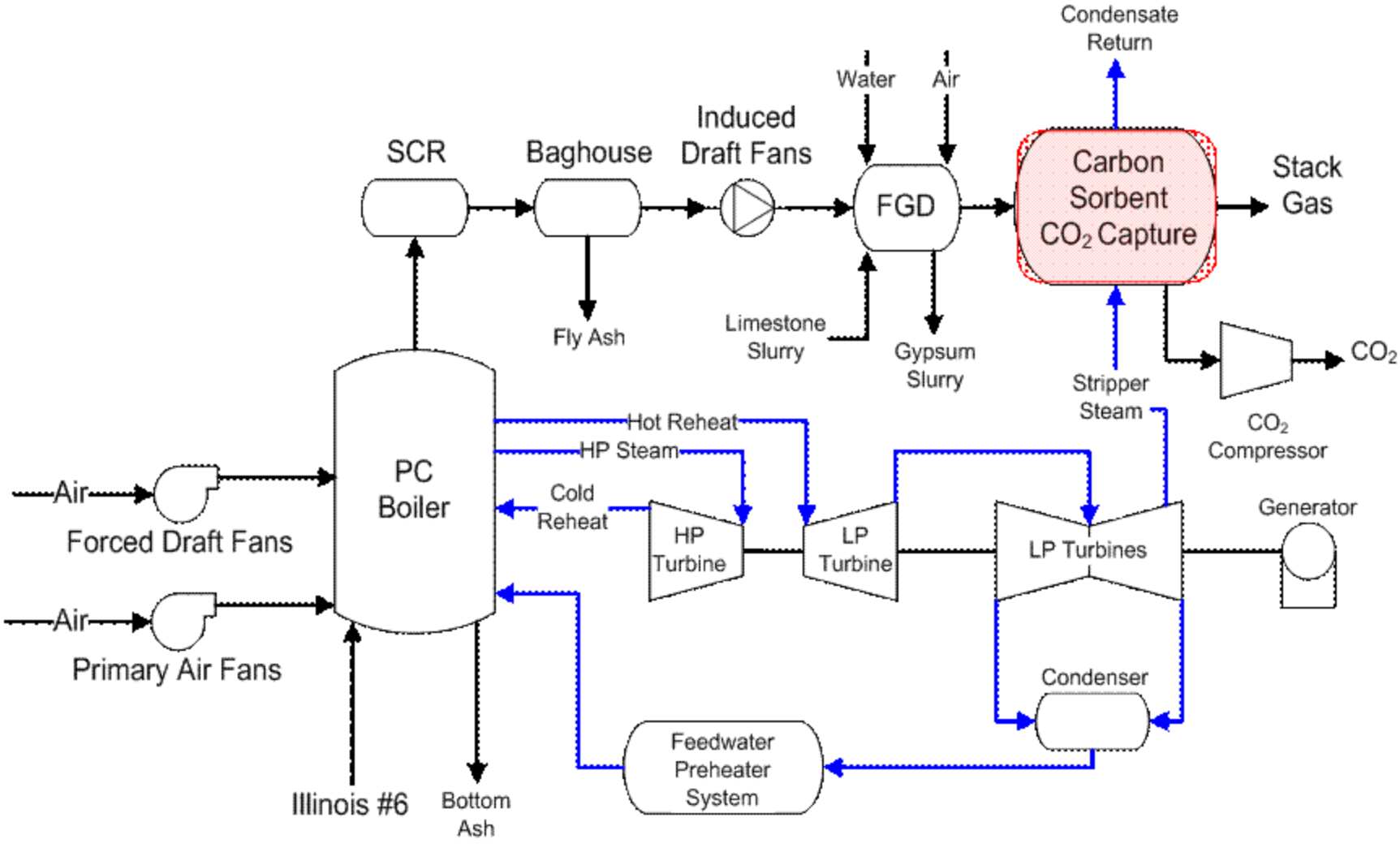
Project Overview

- Participants:
  - SRI International, Menlo Park, CA
  - ATMI, Inc., Danbury, CT
  - National Carbon Capture Center
  - University of Toledo, OH
  - DOE-National Energy Technology Center
- Period of Performance:
  - 10-1-2008 through 11-30-2013
- Funding:
  - U.S.: Department of Energy: $1.95 million
  - Cost share: $0.6 million
  - Total: $2.65 million

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.
- Field Test at the bench-scale level with an actual flue gas from a PC-fired boiler.
- Pilot-scale testing in a future phase

Block Flow Diagram



Basic Principles

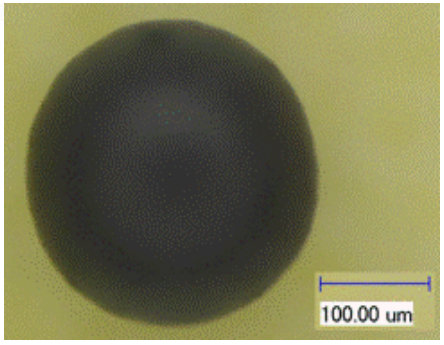
- Adsorption of CO_2 from flue gas on a selective and high capacity carbon sorbent.
- Ability to achieve rapid adsorption and desorption rates (no solid state diffusion limit).
- Minimize thermal energy requirements.
- Ability to produce pure CO_2 stream suitable for compression and pipe line transportation.
- A continuous, falling micro-bead sorbent reactor geometry integrates the adsorber and stripper in a single vertical column
  - Provides a low pressure drop for gas flow and minimize physical handling of the sorbent.

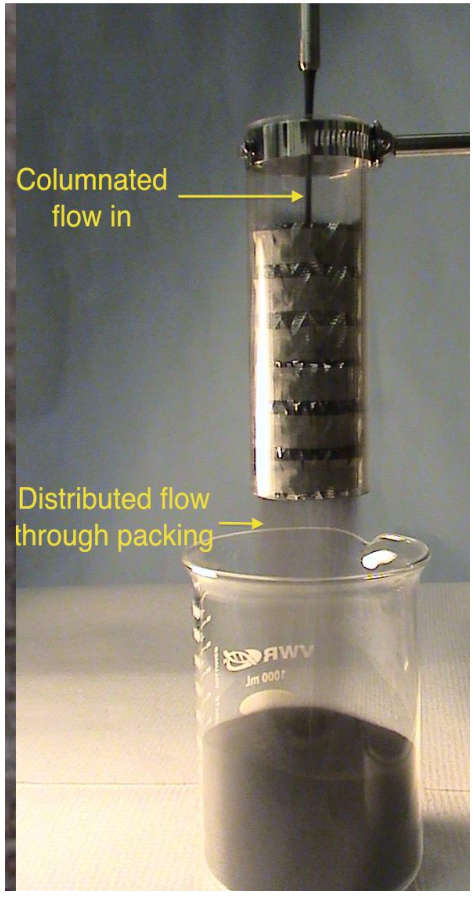
Sorbent – Chemical Properties

- High CO_2 capacity:
  - The sorbent has a high capacity for CO_2 adsorption (20 wt% at 1 atm CO_2) and good selectivity for CO_2 over other flue gas components.
- Rapid adsorption and desorption rates:
  - The adsorption of CO_2 occurs on the micropores of the sorbent with very low activation energy (<5kJ/mole), allowing rapid cycling of the sorbent.
- Low heat of adsorption and desorption:
  - A relatively low heat of sorption (26 to 28 kJ/mole).
- High hydrothermal stability:
  - Direct heating with steam can be used for CO_2 desorption.

Sorbent – Physical Properties

- Mechanical robustness for long lifetime:
  - Hard and attrition resistant; Unusually tough for a high surface area (1600 m^2/g) porous solid.
  - ASTM Test D-5757: Attrition resistance very high.
  - Field test for 7000 cycles – No noticeable attrition.
- Spherical morphology of the sorbent granules:
  - Sorbent spheres (100 to 300 μm) allows a smooth flow.
  - This free-flowing, liquid-like characteristic allows the use of commercially available structural packing.
- Low heat capacity:
  - The low heat capacity of the sorbent (1 J/g/K) and low density (1 g/cm^3) minimizes the thermal energy needed to heat the sorbent to the regeneration temperature.
- High thermal conductivity:
  - The thermal conductivity of 0.8 W/m-K enables rapid thermal equilibrium between the sorbent surface and interior.





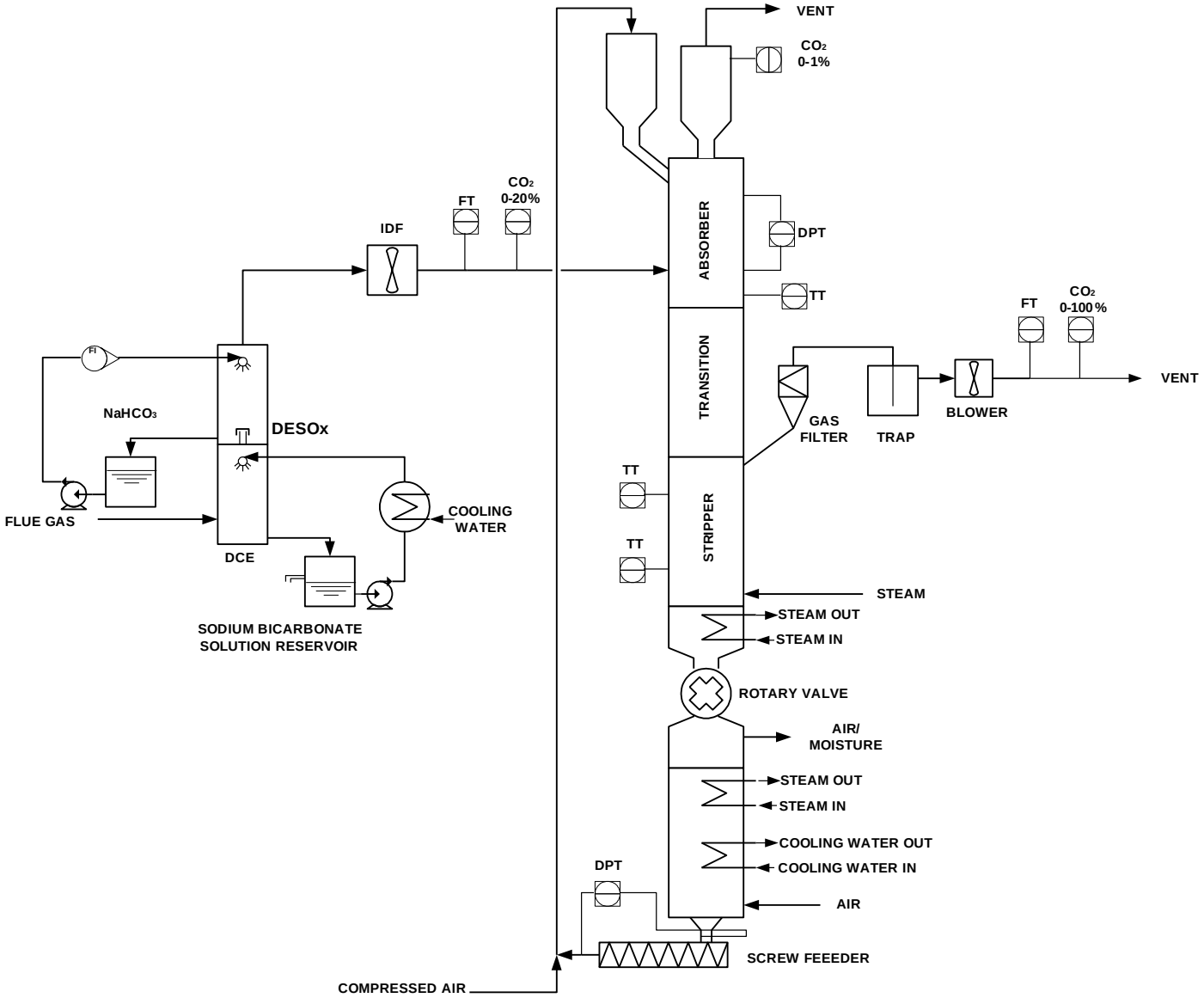
Summary of Previous Reported Results

- Demonstrated an unique sorbent and a reactor geometry for CO_2 capture under simulated flue gas conditions in a 1000-cycle test:
- Developed an unique reactor system
  - Integrated absorber-desorber geometry
  - Minimize solids handling
  - Minimize heat exchanger requirements.
- Performed a 135 h test with a flue gas from a coal-fired boiler at the University of Toledo
- The system was able to reduce the CO_2 level from 4.5% to <0.05% (fully regenerated sorbent).
- We achieved steady-state operation with 90% capture efficiency with >98% CO_2 purity in the product gas.
- Sorbent flow: Smooth!; Typical cycle time: ~1 min.
- No significant operational issues were observed (except for cold-weather related problems – not process related).

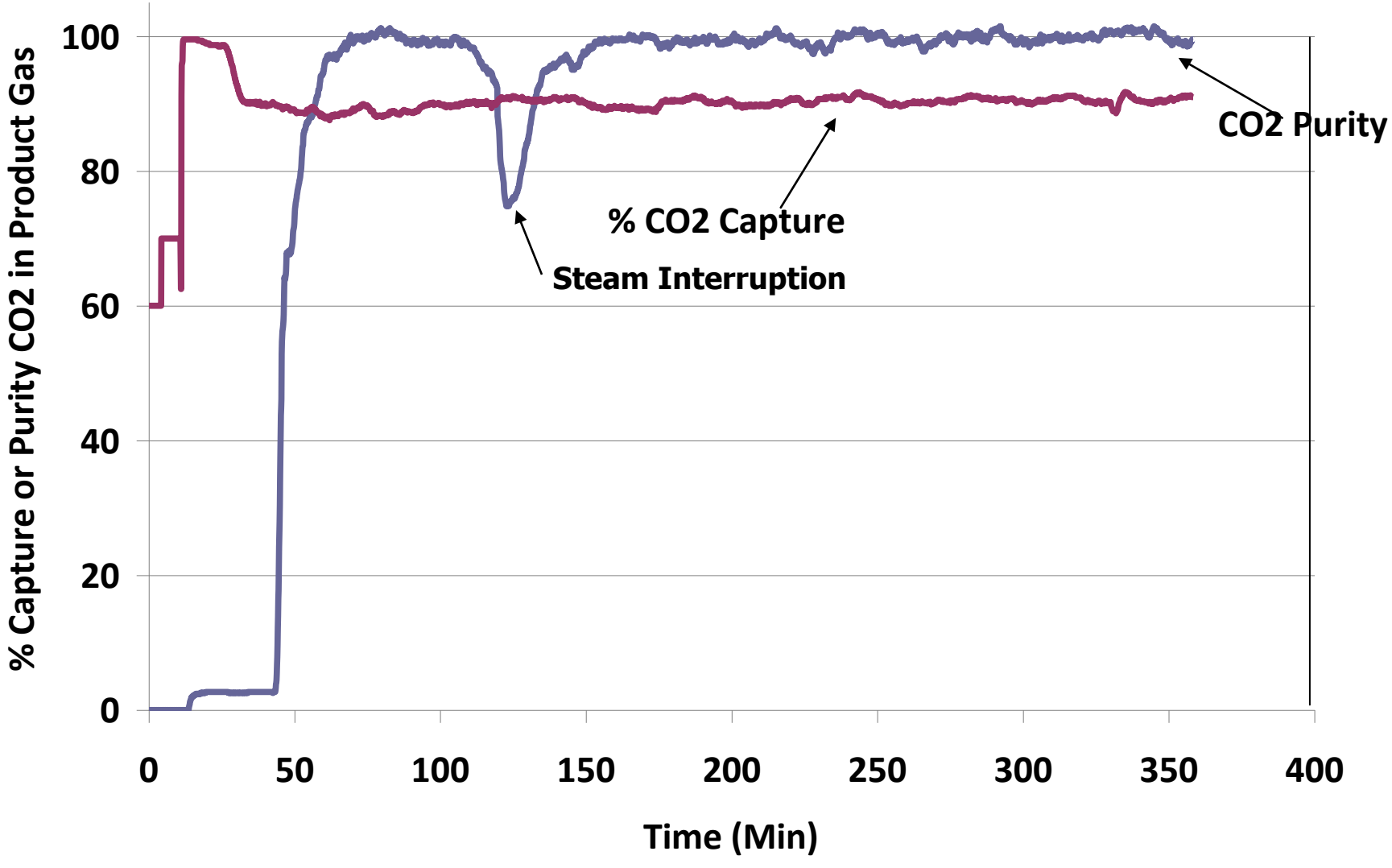
Operation at UT

- The system was operated during the day time from 8 AM to 7 PM, about 6 days a week for one month (including shake-down runs).
- The flue gas flow rate was about 200 standard liters/min.
- CO_2 concentration: 4.5% v/v
- SO_2 concentration: 60 ppm reduced to ~1 ppm with the use of a FGD with sodium bicarbonate.
- NOx control was not practiced.
- Pressure drop across the adsorber: 0.4 inch WC.
- Total hours of operation: 130 hours (7,000 cycles)

Schematic Diagram of the System at UT



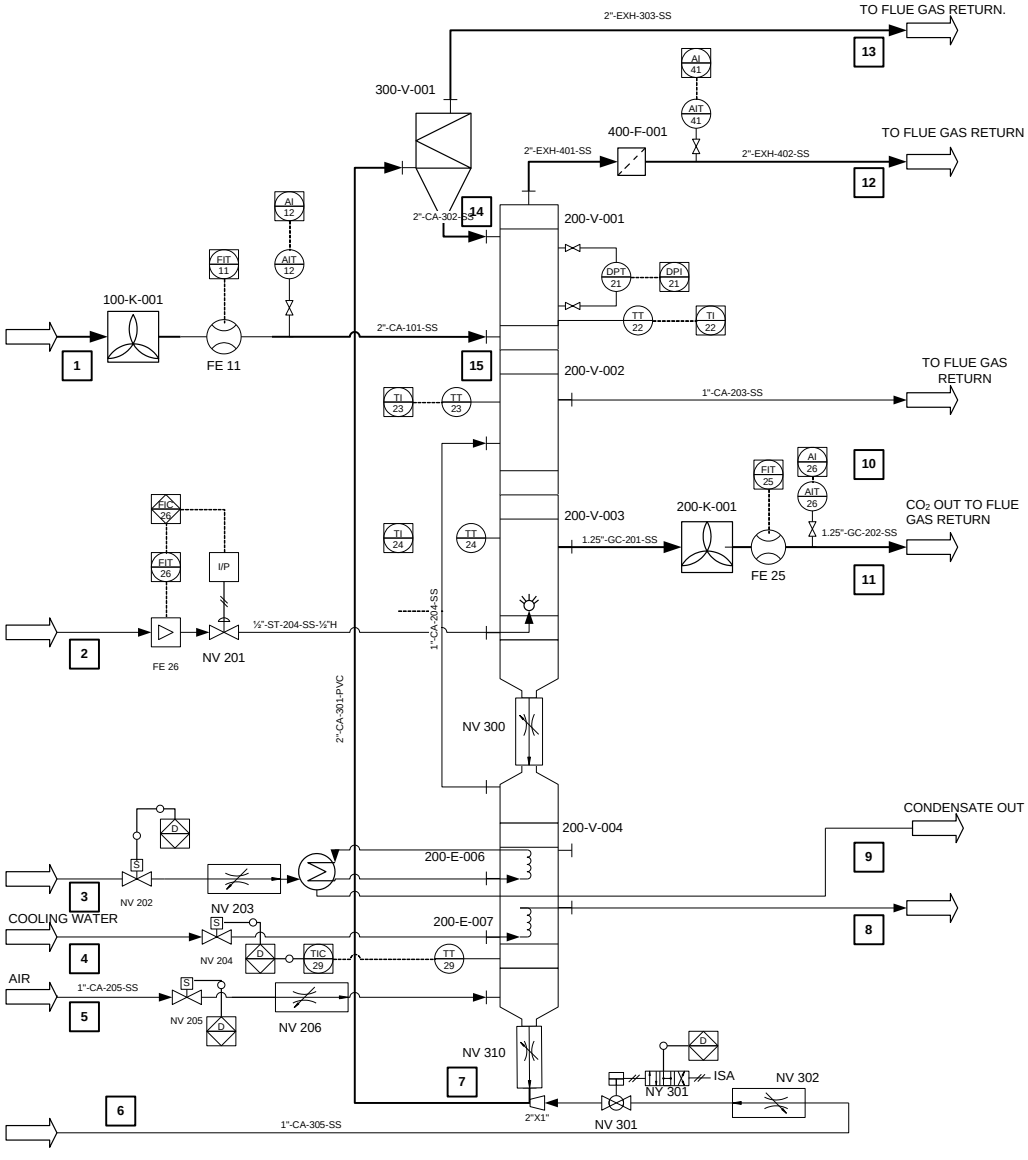
CO2 Capture Efficiency and Product Gas Purity

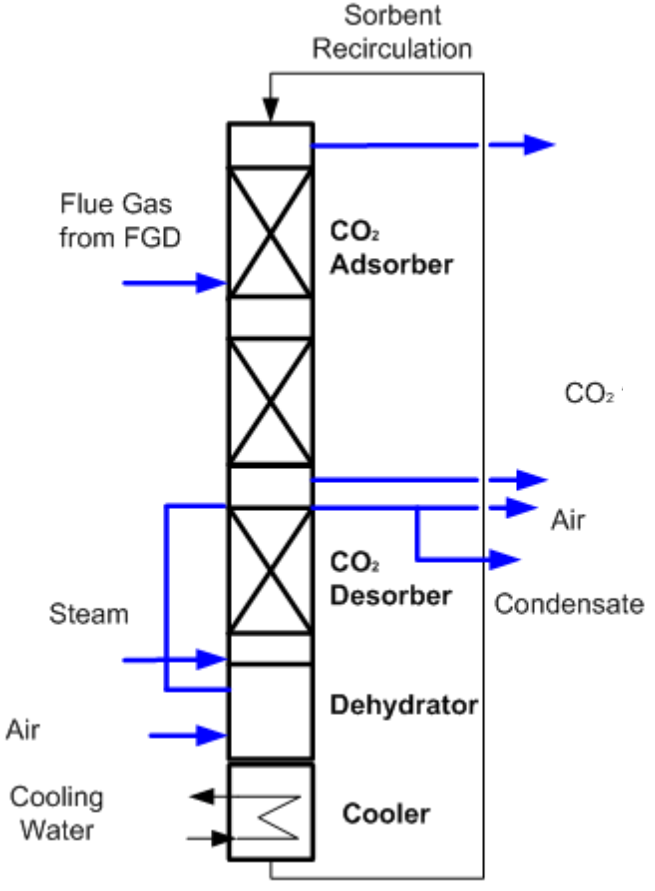


Objectives of Testing at NCCC

- Testing with a flue gas from a PC-fired boiler.
- Test goal: 150 h of continuous operation; 1000 h of total operation.
- Parameters to be tested:
  - Effect of flue gas velocity;
  - Effect of flue gas contaminants;
  - Materials of construction with coupon testing;
  - Efficiency of thermal recovery.

System for Tests at NCCC





Design of Integrated Reactor for Testing at NCCC

- System Dimensions:
  - 1.5 ft square x 50 ft tall
  - Adsorber: 15-ft tall; Stripper: 15-ft tall
  - Made of stainless steel using HVAC design concept.
- A heat exchanger to recover heat from hot, regenerated sorbent and use it to preheat the sorbent from the adsorber.
- Evaluation of sorbent metering equipment.
- Nominal flue gas flow: 70 cfm.
- Goal: 90% CO_2 and >98% CO_2 purity.
- CO_2 capture capacity: ~1 ton/day.

Section of the Adsorber at SRI

Adsorber Section

Hopper with a Pinch Valve

Support Structure at SRI Pad

Current Status

- Key components are procured.
- Support structure has been fabricated.
- System is partially assembled and will be shipped shortly.
- Safety review has been completed with participants from SRI and NCCC.
- Final agreement with NCCC is expected shortly.
- Installation at NCCC is expected in August 2013.

Challenges in the Field Test

- Timely assembly at the new site
  - Partially assembled sections raised and bolted together.
- Utility connections
  - Flue gas, steam, air, water, and electricity.
  - Most connecting points are flanged.
- Sensor and data acquisition
  - Multiple and redundant temperature and pressure sensors.
- Weather related problems
  - We do not expect cold weather issues experienced at the University of Toledo; heavy rain may be an issue.

Future Plans

- Field Testing:
  - Field test, at a pilot-scale (1 ton CO_2/h), the process using a flue gas from an operating pulverized coal-fired boiler.
- Technology Transfer
  - SRI and ATMI are in touch with several utility and chemical companies for further development.

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