Update on Pilot Unit of Sorbent Based Post-Combustion CO_2 Capture
Project # DE-FE0012870

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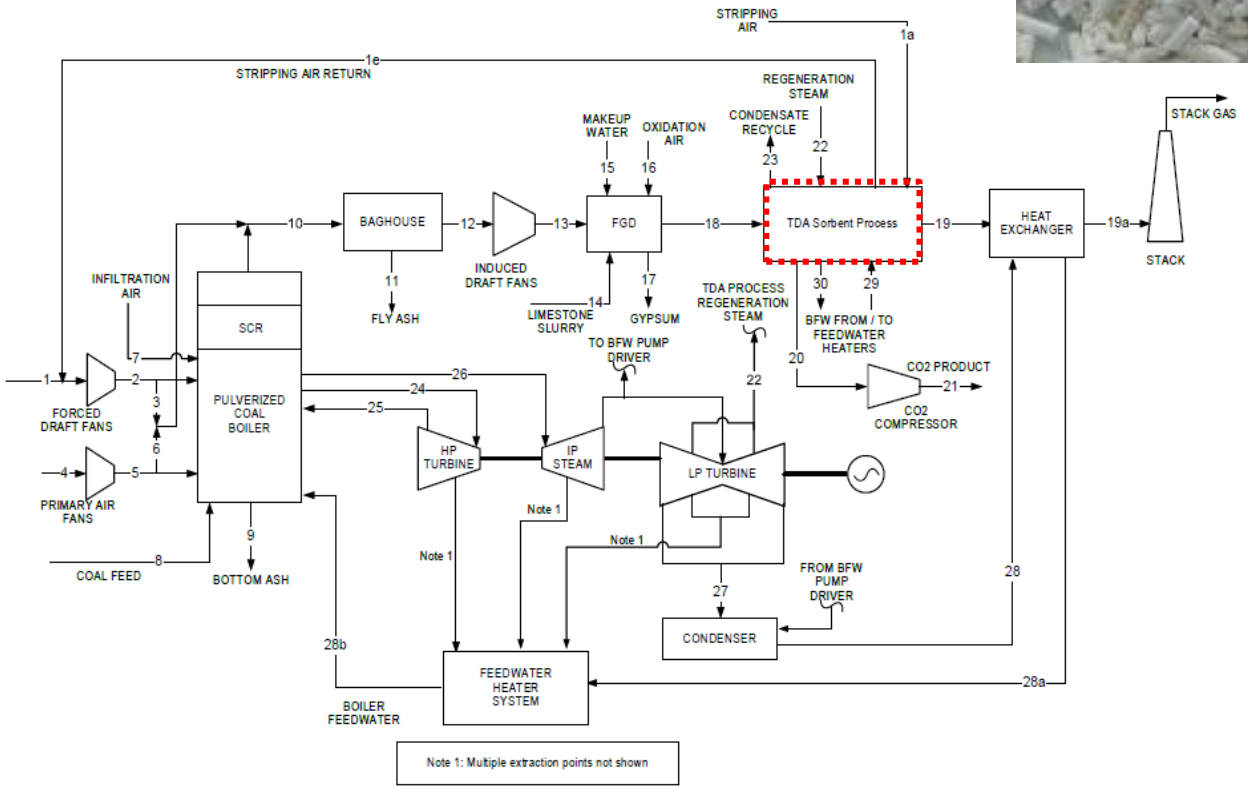
Project Scope

DoE Project DE-FE0012870
Funding - Total Project $6,480,377

- **Budget Period 1: Optimization & Design**
- **Budget Period 2: Construction & Installation**
  - Pilot Unit Construction
  - Sorbent Production Scale-up and Quality Assurance
  - Pilot Unit Installation
- **Budget Period 3: Shakedown & Operation**

Project Objectives

- The objective is to develop **solid sorbent** capture technology that captures CO_2 at less than $40 per tonne not including TS&M.



TDA CO_2 Capture on Supercritical 550 MW plant

Project Overview

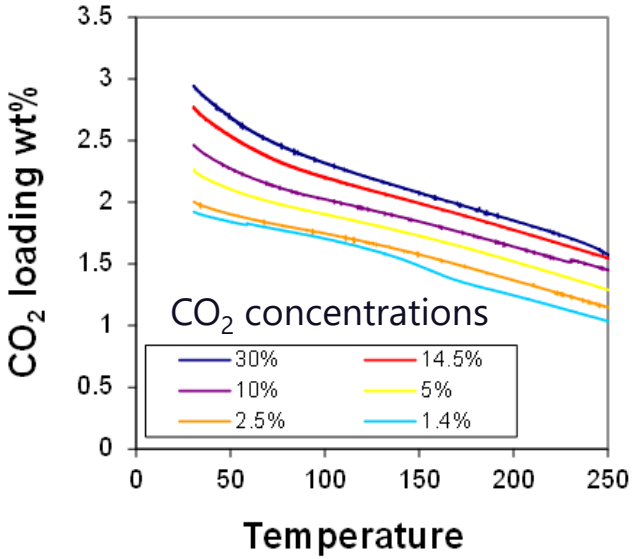
- Goals of NCCC testing
  - Demonstrate alkalized alumina sorbent technology under realistic conditions at 0.5 MW_e (~10 tpd CO_2) scale on coal flue gas) to collect data necessary for scale up to next level plant.
  - Demonstrate sorbent technology on coal fuel gas and diluted flue gas to simulate NG flue gas
- Planned Testing
  - 1.5 month parametric testing and 2 months steady state testing

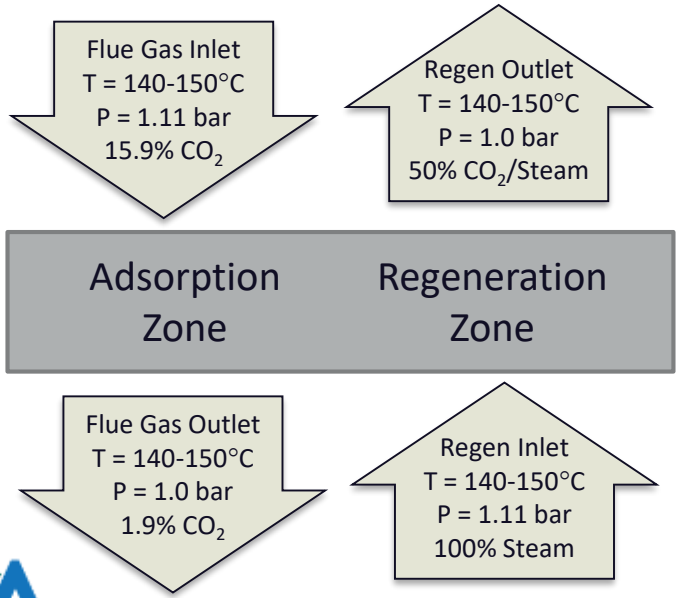
National Carbon Capture Center located at the E.C. Gaston power plant (Wilsonville, Alabama)

Technical Background

TDA Research has developed:

- A low-cost, alkalized alumina adsorbent
- A CO_2 capture process designed specifically for this sorbent
- A unique CO_2 capture process to run adsorption and regeneration at near isothermal conditions

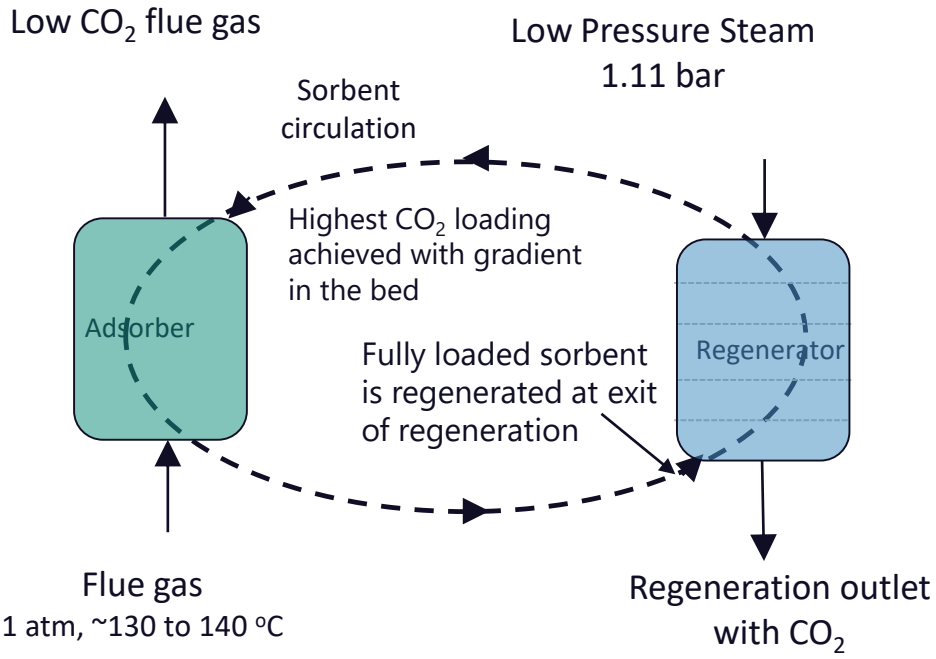




Heat of adsorption ranges from 3 kcal/mole at higher CO_2 concentrations of 10-14%, to 10.3 kcal/mole at CO_2 concentrations of 1-5%

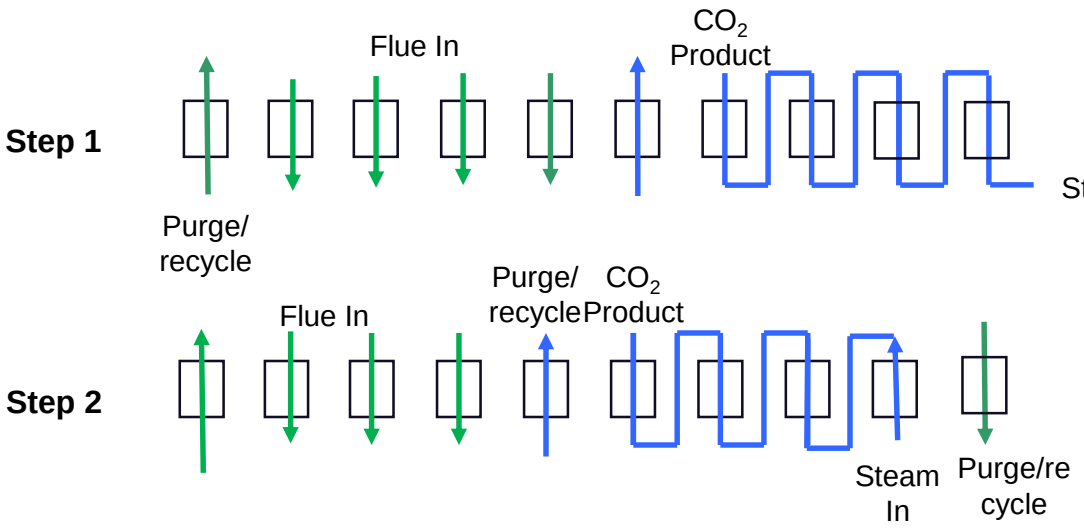
Adsorbents

- **Adsorbents loosely bind CO_2 to the surface**
  - Regeneration is fast and with low desorption energy requirement
  - High concentration of CO_2 during desorption
- **Adsorbents operate along a concentration gradient**
  - They absorb more CO_2 when the concentration is higher than when the concentration is lower
- **Optimum bed design is counter-flow**
  - Maximizes the loading on the adsorbent by having the adsorbent contact the gas stream with the highest CO_2 concentration at the end of its reactor residence time



Simulated Moving Bed Process

- **Multiple Fixed Bed Contactor**
  - Provides counter-flow contact between the solids and gases
- **Beds cycle between adsorption and regeneration functions**
- **Gas flows in parallel through adsorption beds and in series across regeneration beds**



Advantages over moving bed

- Moving bed had expensive conveyors, although the beds would be smaller
- Selected Multiple fixed bed design
  - ✓ Basic duct work
  - ✓ Low cost construction
  - ✓ Simple bed design
  - ✓ Eliminates parasitic power needed to move the sorbent
- Lower overall cost than moving beds

Bench-scale Testing at TDA

- Process design optimized
- Expanded from 8 bed to 10 bed process demonstrated in bench-scale unit at TDA
- System also used for sorbent evaluation
- Multiple patents on the process: US9539540B2, US9446343B2 US9504955B2, US9527029B2

Process design demonstrated in bench-scale system at TDA

Schedule and Milestones

- Completed Milestones
  - Process Flow Pattern Optimization
  - System Design and Engineering
  - Pilot Unit Construction
  - Sorbent Production
  - Pilot Unit Installation and Shakedown
- Next Milestones
  - 1.5 Months of Parametric Testing (In Progress)
  - 2 Months of Steady State Testing
  - Update Techno Economics Analysis

Test Plan

- The primary objective of the pilot unit field tests is to demonstrate the technical merits of this sorbent-based CO_2 capture process at 5000 lb/hr for 0.5 MW
- Optimize cycle parameters to achieve the following goals:
  - Minimize the amount of regeneration steam used
  - Maximize the flue gas flow rate through the TDA system
- We will also evaluate the process under both coal derived flue gas and diluted flue gas (simulated natural gas conditions)
- Demonstrate cyclic operation at steady state.
- Evaluation at 90% capture and optimization at lower capture targets

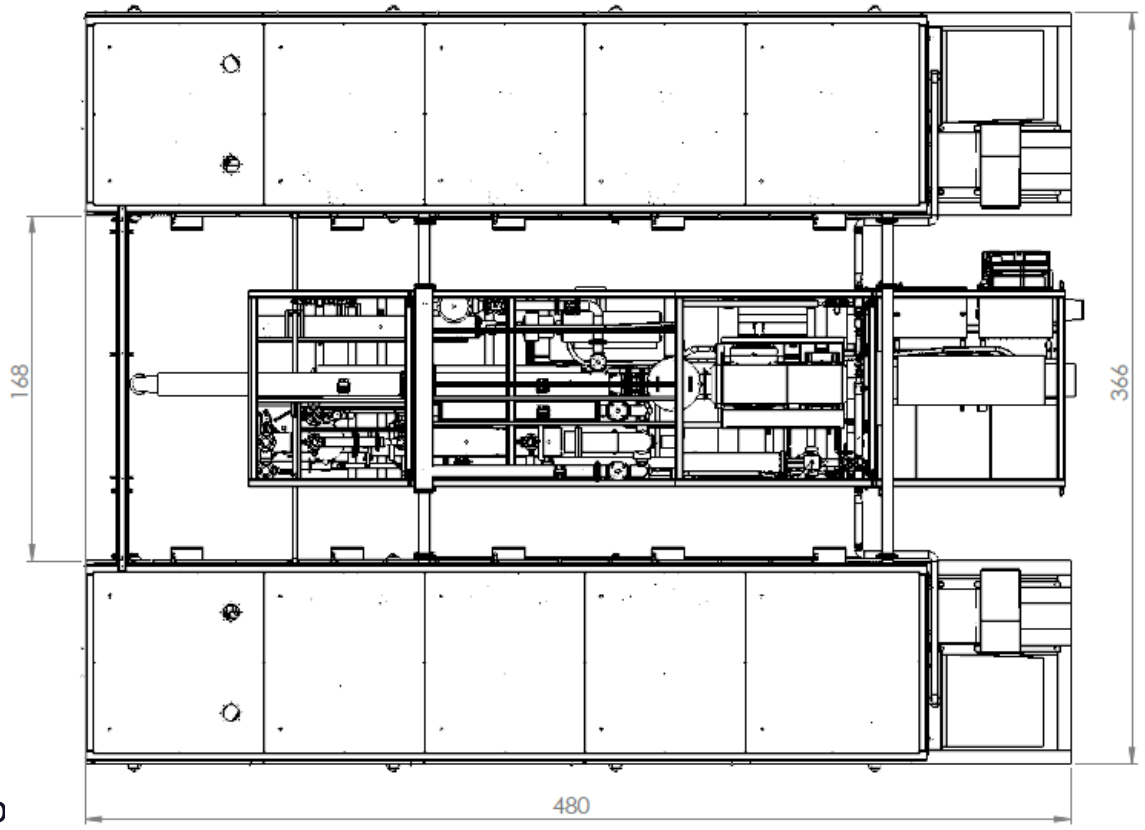
Pilot Unit System
0.5 MW Demonstration

2 Sorbent Bed Trailers

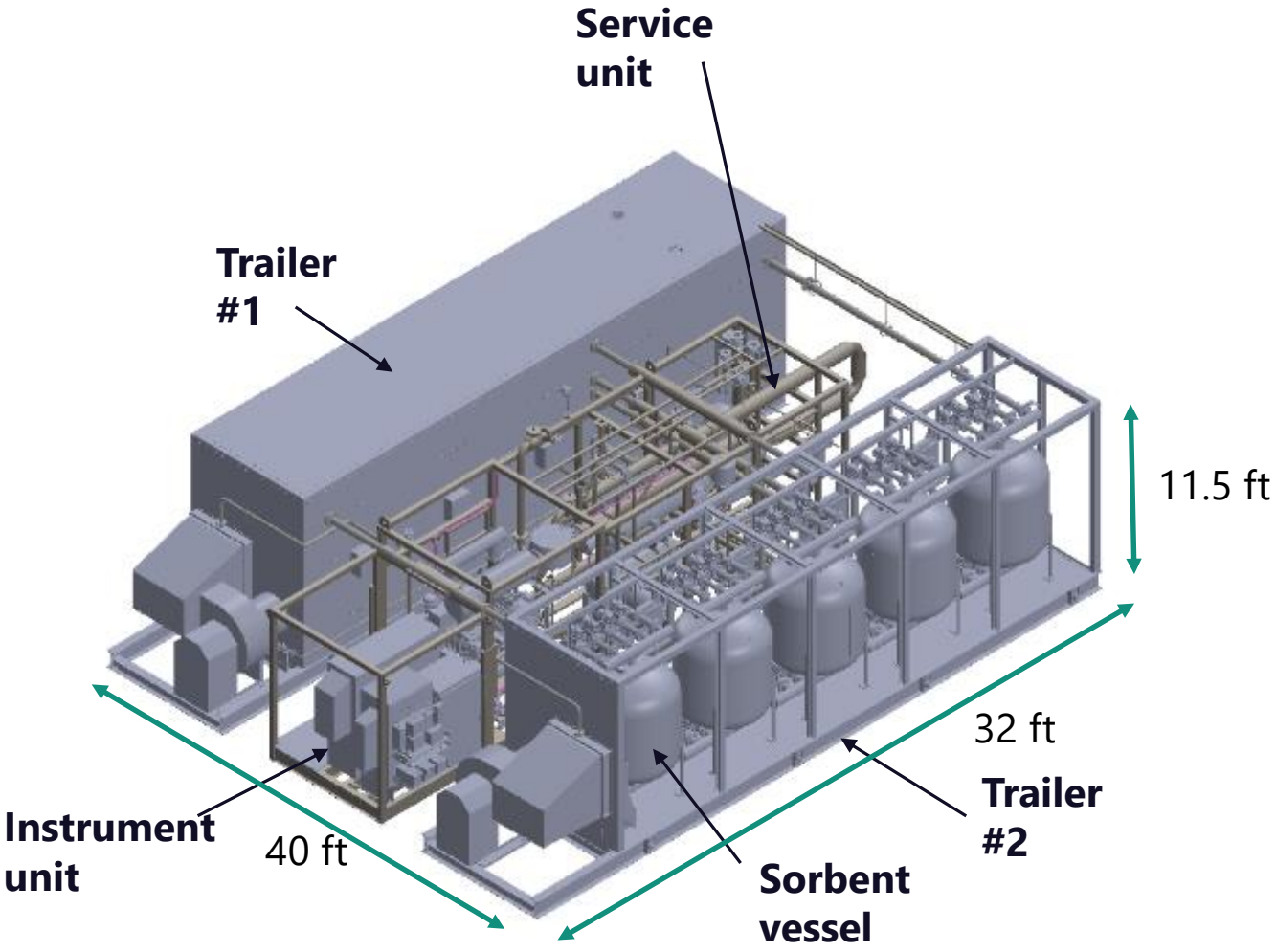
- Sorbent trailers house 10 sorbent beds (5 in each trailer) and manifold piping
- Each trailer is insulated and heated to provide an isothermal environment

Service Unit/Instrument Trailer

- Pressure, temperature and flow control for process gases
- Each process gas routed to both sorbent bed trailers
- Houses the control system and all electrical components for power allocation
- A full suite of on-board analyzers to evaluate system performance



Pilot Unit Skids

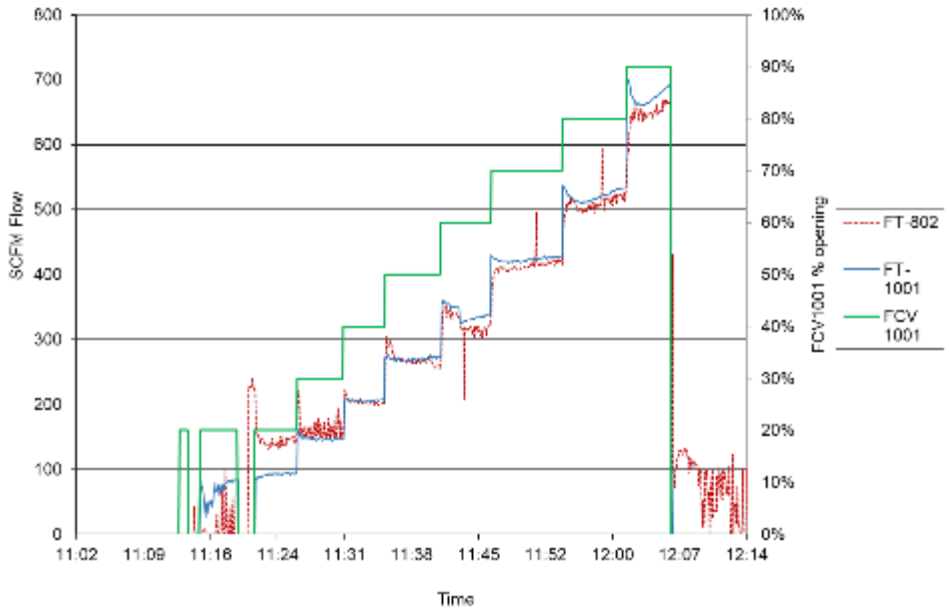


Sorbent Loading

- Scaled up sorbent had good initial performance but unexpected (poor) performance in extended cycling tests
- The sorbent had to be reprocessed by the manufacturer at their cost
- Because of loss in reprocessing, two beds were filled with modified commercial sorbent material
- Sorbent was replaced in one bed due to being flooded with steam in shakedown
- Expect variation in the sorbent between beds
- Beds are being bench-marked

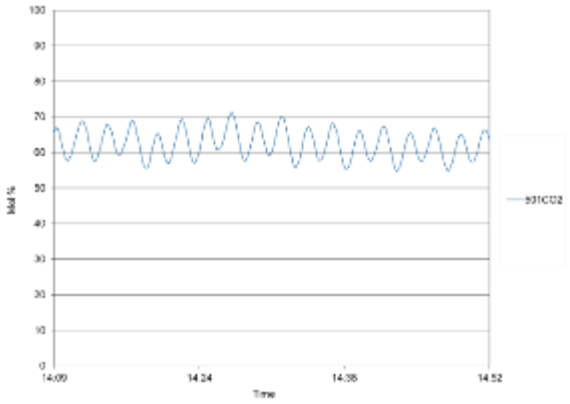
Shakedown Activities

- Flow meters were checked and steam flow meter issue was solved.
- Pneumatic valves installed to control the flow to the reactors, and all were confirmed to operate as needed.

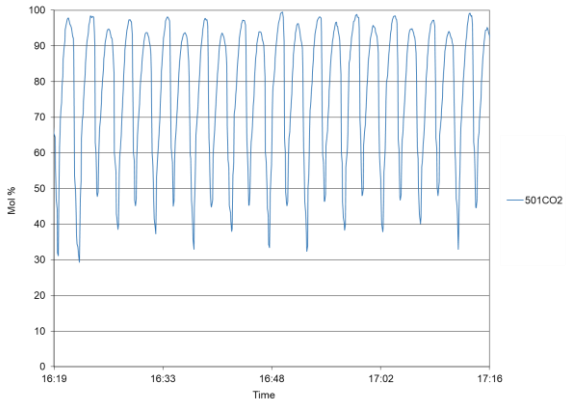


Shakedown Activities (cont)

- Humidity sensor operation was successfully demonstrated
- CO_2 and O_2 analyzers calibrated
- Gas sampling rate optimized to get accurate real time concentration
- Added another chiller to the sampling line



0.5 L/min sampling rate



1.0 L/min sampling rate

Shakedown Activities (cont)

- All control valves were checked and function properly.
- Reactor cycling program tested.
- Functionality of each flow process demonstrated
- Two sorbent trailers were successfully kept hot by the automated system overnight without operator present.

Sorbent Beds brought Online

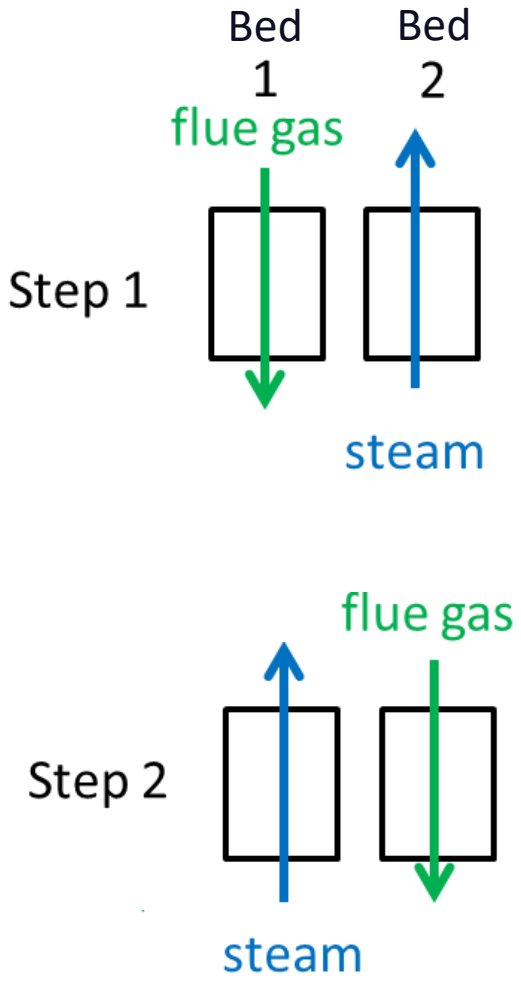
- Fresh sorbent adsorbs water when brought online
  - Adsorption process is exothermic
- To control temperature exotherm in large beds, sorbent is conditioned to operation feeds
- Beds are hydrated in staged process
- Procedure developed was demonstrated to work well and control initial temperature

System Operation

- Process operations demonstrated sequentially
- Simple batch mode operation run with each beds in pairs
  - One bed on adsorption and one bed on regeneration
- Additional process step features added one at a time

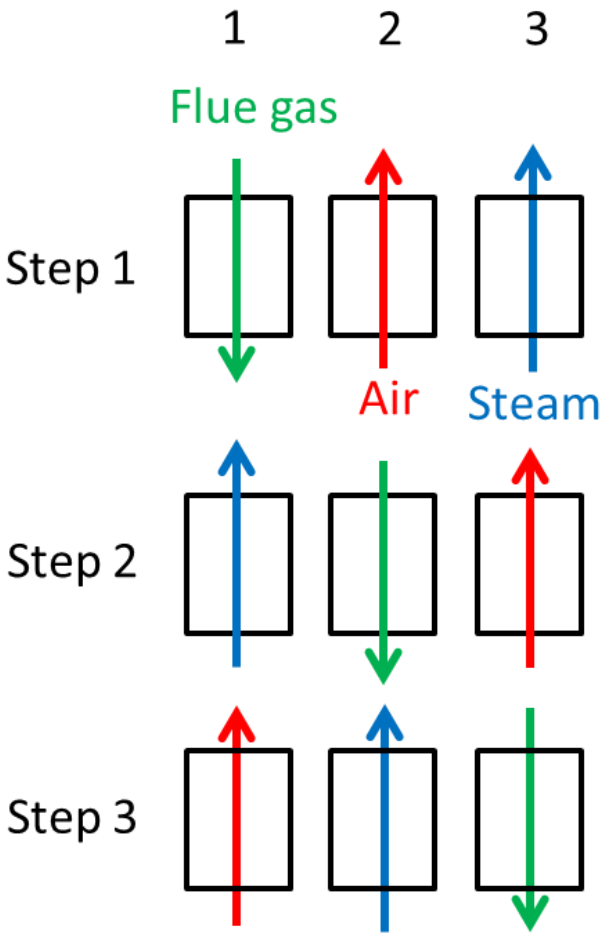
2-Bed Test

- Initial tests conducted with 2-bed operation
- Flue gas flowrate equivalent to 0.3 MW (60% of design flow) with only 20% of the sorbent
- Achieved 75% capture and showed good functionality of the system hardware
- Dilution of flue gas to simulated NG flue gas also tested in 2-bed cycle

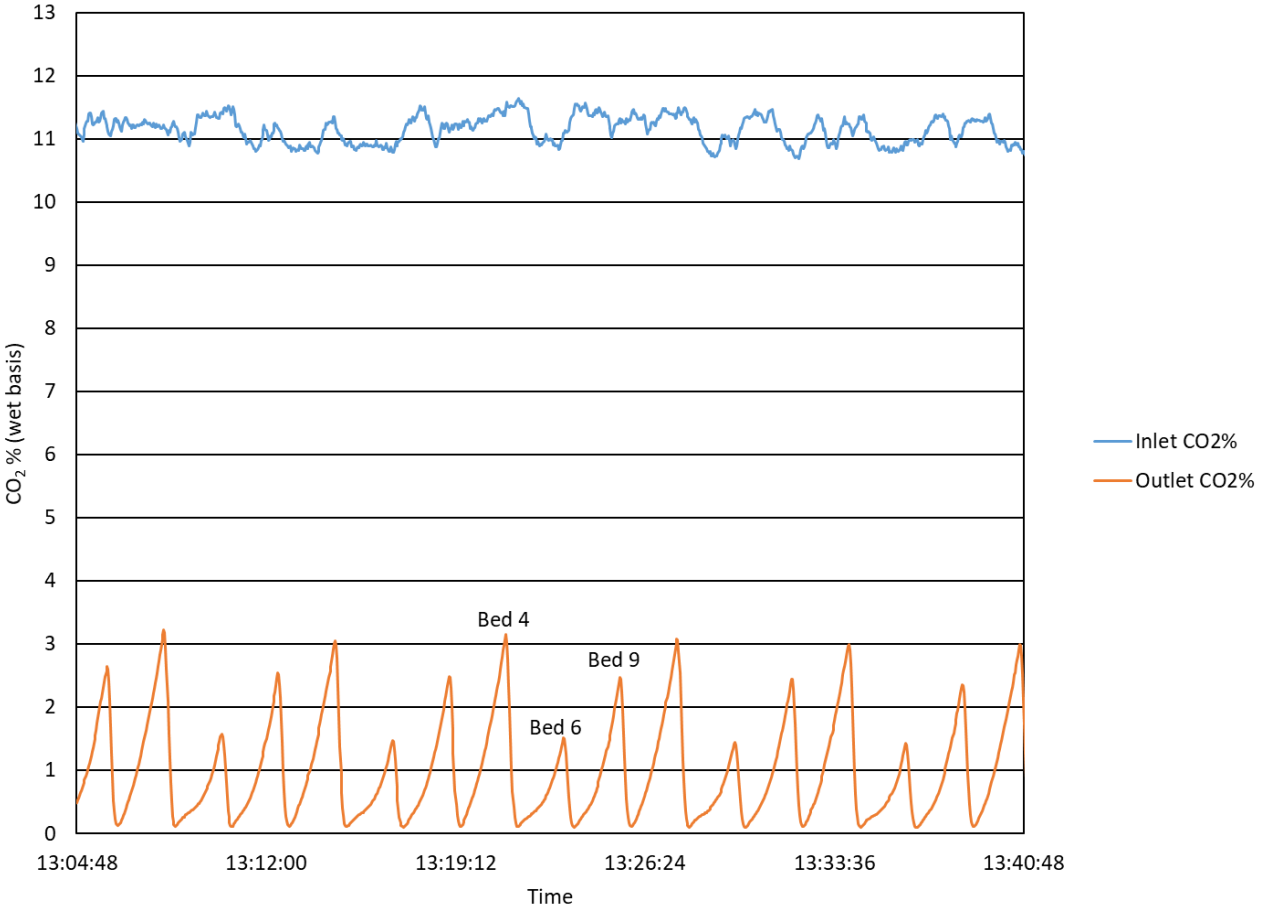


3-Bed Test

- Strip step is designed to further regenerate the sorbent.
- Flue gas of equivalent to 0.3 MW (60% of design flow) was used in the comparison.
- The CO_2 capture rate increased from 75% for 2-bed test to 89% for 3-bed test.



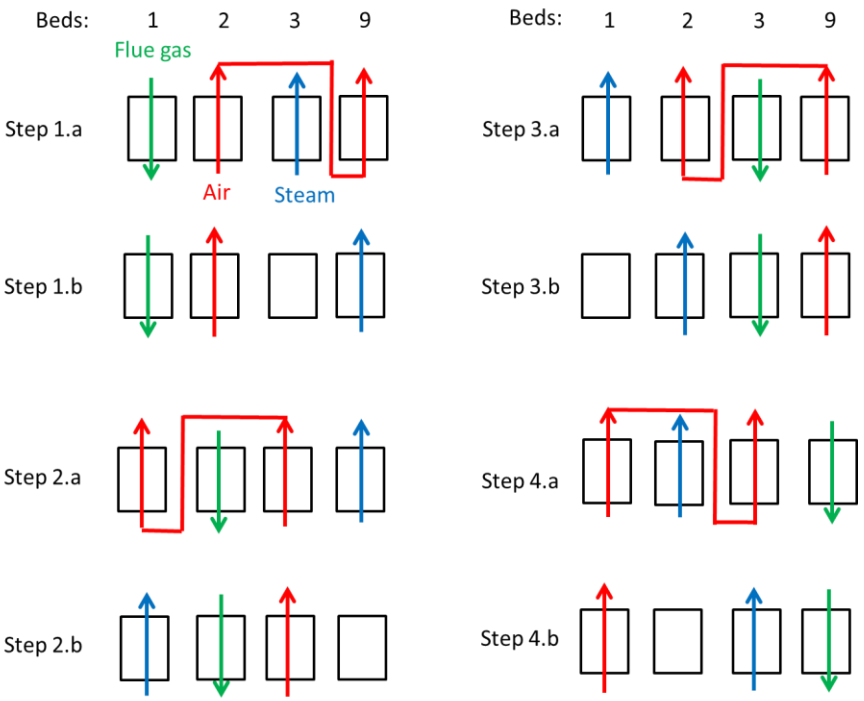
3- Bed Test



- Best capture rate with Bed 6 (>90% Capture).

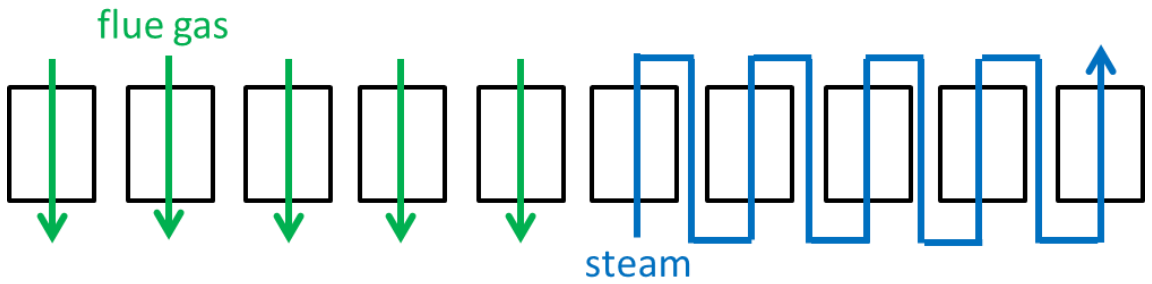
4-Bed Test

- Steam saver step, transferring steam from a fully regenerated bed to a bed just finished adsorption, is designed to reduce steam consumption.
- Flue gas of equivalent to 0.3 MW (60% of design flow) was used in the comparison.
- The same CO_2 capture rate as 3-bed test was achieved for 4-bed test with 16% less steam (on a per mole of CO_2 captured).



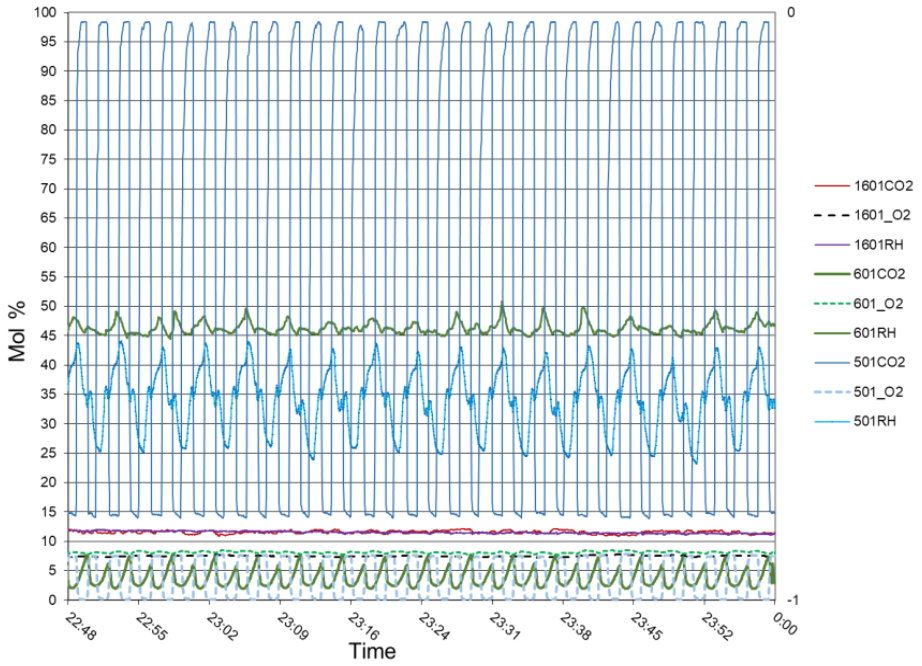
5+5 Test

- 5 beds are used in adsorption and gas flows in parallel.
- 5 beds are used in regeneration and gas flows in series.
- Flue gas of equivalent to 0.5 MW (100% of design flow) was tested.
- 84% CO_2 capture rate was achieved under 5+5 basic cycle.
- Individual bed performance varied.



Overnight Option

- Stable operation demonstrated overnight without operator present
- Two bed cyclic operation tested
- No issues



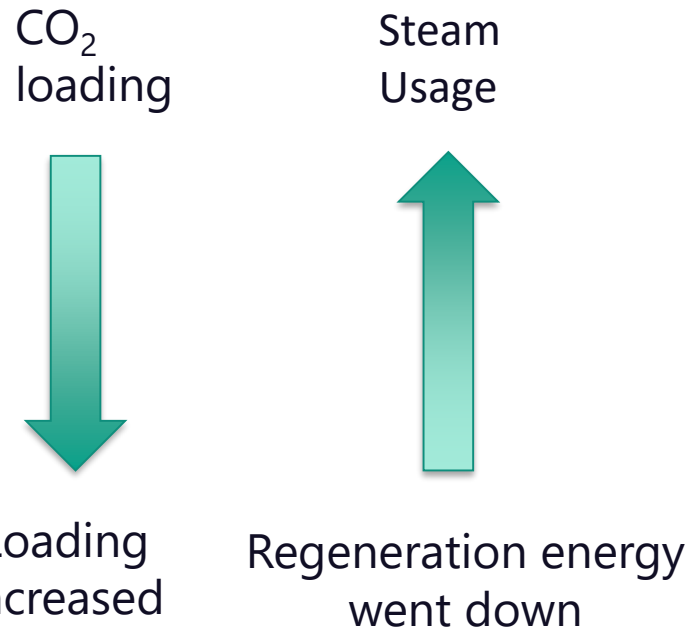
Full Process Scheme Testing

- Testing with full process flow pattern
- Optimized cycles has several features to benefit performance

Feature	Advantage	Benefit
10 beds	Additional regeneration stages	• Additional stripping for same steam usage • Beds needed for transition steps
Purge	Additional regeneration	• Higher capture rate • Less steam usage
Steam saver with controlled flow and timing	Steam recycled back to regeneration side to rehydrate bed can be optimized in controlled manner	• Steam usage decreased • Steam saver can tuned for maximize benefit

Comparison of Process Cycles at Pilot Unit 10 Bed - 0.5 MW

Flow pattern	Capture rate %
5 ads + 5 reg	54%
With Purge	82%
With Purge & Steam saver	**92%**



Optimized process significantly increases capture and decreases steam usage

Summary

- TDA's CO_2 capture system uses an alkalized alumina sorbent and a process designed specifically for this sorbent.
- Pilot Unit installed at NCCC and comprehensive hardware and instrumentation shakedown completed
- A procedure was developed and instituted for start-up of the sorbent beds. This procedure controls the temperature rise during initial hydration of the sorbent
- The operation of our different sequences of flow operation were demonstrated. Each was tested individually..
  - Capture rate increased from the 70% range up to as high as 93% with additional cycle features in 3 bed tests.

Summary (cont)

- To simulate natural gas flue gas, which contains less CO_2 than coal fired flue gas, we designed our apparatus the ability to dilute the coal flue gas with air. The system ran with simulated natural flue gas without issue.
- TDA successfully ran an automated overnight experiment with no issues.
- All ten beds were run in a simple cycle with five beds on adsorption and five beds on regeneration (5+5 cycle). This test was run with 0.5 MW equivalent flue gas.
- Features of full flow pattern demonstrated in 0.5 MW test
  - With same regeneration steam, adsorption capture increased from 54% to 92%

Acknowledgements

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- DoE: Andy O'Palko and Lynn Brickett
- NCCC team