Advanced Structured Adsorbent Architectures for Transformational Carbon Dioxide Capture Performance

primary project goal

Electricore, teamed with Svante and Susteon, is optimizing Svante's transformational VeloxoTherm™ Technology via the development and field testing of an advanced structured adsorbent bed (SAB) to enhance its performance and lifetime. The project team will select, synthesize at large scale, and characterize tailored solid adsorbents, optimize the SAB laminate and Rotary Adsorption Machine (RAM) contactor structure and geometry, develop a final process cycle using process simulations and state-of-the-art modelling, and complete dynamic bench-scale testing with natural gas-fired boiler flue gas and cement plant flue gas.

technical goals

- Synthesis at large scale (greater than 500 kg) of tailored solid adsorbents, including a MOF.
- Optimize the design and fabrication of the segmented bed with, possibly, different geometries to optimized sorbent utilization and keep low pressure drop and laminar flow.
- Optimize the rapid cycle temperature swing adsorption (RC-TSA) process to increase the CO_2 capture efficiency of two different sorbents in the same cycle.
- Develop a segmented bed configuration for both low (less than 12%) and high (greater than or equal to 12%) CO_2 concentration.
- Build and test segmented beds using multi-bed field demonstration units with flue gas from a natural gas-fired boiler (low CO_2 concentration) and from a cement plant (high concentration).
- Assess the techno-economic performance of the technology integrated into a 550-megawatt-electric (MWe) coal-fired power plant.

technical content

The project team is developing an advanced structured adsorbent bed geometry and rotary contactor architecture including segmented layers bed for post-combustion CO_2 capture in order to develop Svante's Mark II VeloxoTherm technology. Two configurations of segmented beds will be explored: low concentration (less than 12% CO_2) and high concentration (greater than 12% CO_2). The low-concentration configuration will be tested in-house in a multi-bed process demonstration unit (PDU) to demonstrate key performance indicators (KPIs), such as recovery, product purity, regeneration energy, lifetime, and the integrated system's productivity. The second configuration of segmented beds, for higher CO_2 concentration, will be tested at a 1-tonne-per-day (TPD) unit at an industrial site (cement plant) to provide bench-scale validation of performance in an industrial setting.

program area:
Point Source Carbon Capture

ending scale:
Bench Scale

application:
Post-Combustion Power Generation PSC

key technology:
Sorbents

project focus:
Structured Sorbent Beds

participant:
Electricore Inc.

project number:
FE0031732

predecessor projects:
N/A

NETL project manager:
Carl Laird
carl.laird@netl.doe.gov

principal investigator:
Deborah Jelen
Electricore Inc.
jelen@electricore.org

partners:
Svante Inc.; Susteon, Inc.

start date:
05.01.2019

percent complete:
80%

The segmented bed configuration combines two or more sorbents in the direction of the sorption. As a result of the counter-flow of the steam and flue gas streams, and the fast process cycle (less than 60 seconds), temperature and relative humidity (RH) conditions are different throughout the length of the bed with some areas suffering more from oxidation and some areas with higher RH, which could decrease the CO_2 capacity of a metal organic framework (MOF) sorbent. The segmented bed concept permits the use of the optimal sorbent for the given local condition (Figure 1). The advantage of the segmented bed is the ease of retrofitting to existing plants design and to extend the lifetime and performance.

The process and segmented bed design needs to be optimized to efficiently use the same process for both the adsorption, desorption, and regeneration, keeping equivalent CO_2 capacity for each sorbent section, minimizing the flow resistance and loss of laminar at the interface and ease of manufacturing. Overall, this process has potential for increased sorbent CO_2 capacity, increased lifetime, and reduced steam demands.

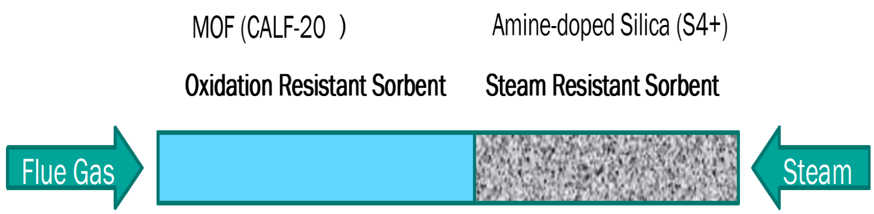

Figure 1: Typical example of the segmented bed concept design.

Optimization of the segmented bed geometry and process is being tested in a single-bed sorbent test using simulated coal-fired flue gas in the Svante Variable Test Station (VTS) shown in Figure 2a, at a scale of approximately 1–10 kg of CO_2/day captured. Afterwards, the Mark II advanced structure will be tested using the VeloxoTherm process with a multi-bed testing station. The low-concentration series will be tested in the Svante rotating adsorption machine in the PDU that is coupled with a natural gas-fired boiler for testing at a maximum of 10 kg of CO_2/day captured. The high-concentration series will be tested in the 1-TPD field unit running flue gas from a Lafarge cement plant in Richmond, Canada.

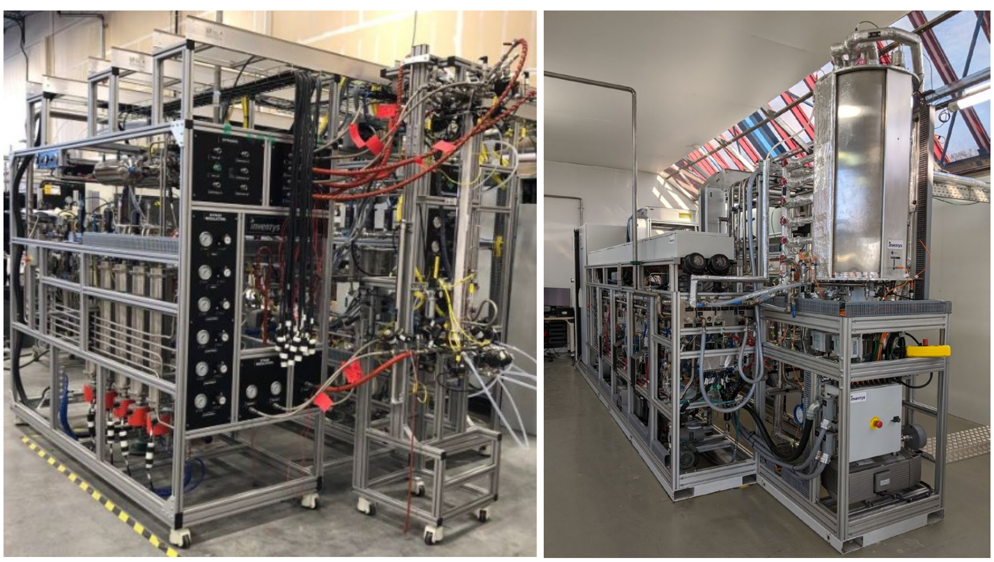

Figure 2: The variable test station at Svante (VTS, left) and the Process Demonstration Unit (PDU, right).

Figure 3: CO_2MENT field Unit (1 TPD) at a Lafarge cement plant in Richmond BC showing the pre-treatment system and capture plant (left) and the RAM showing the beds (right).

The sorbent and process parameters are provided in Table 1.

TABLE 1: SORBENT PROCESS PARAMETERS

Sorbent	Units	Current R&D Value	Target R&D Value
True Density @ STP	kg/m^3	350-380	350-380
Bulk Density	kg/m^3	N/A	N/A
Average Particle Diameter	mm	0.31-0,35	0.31-0.25
Particle Void Fraction	m^3/m^3	N/A	N/A
Packing Density	m^2/m^3	2,300-2,500	2,300-2,500
Solid Heat Capacity @ STP	kJ/kg-K	1.4-1.6	1.4-1.6
Crush Strength	kg$_f$	N/A	N/A
Manufacturing Cost for Sorbent	$/kg	30-35	20-25
Adsorption			
Pressure	bar	1-1.1	1-1.1
Temperature	°C	50	50
Equilibrium Loading (20% CO2)	g mol CO_2/kg	1.7-1.8	1.9-2.0
Heat of Adsorption	kJ/mol CO_2	35-38	35-38
Desorption			
Pressure	bar	0,8-1.0	0.8-1.0
Temperature	°C	110-120	110-140
Equilibrium CO_2 Loading (20% CO2)	g mol CO_2/kg	0.3-0.4	0.4-0.5
Heat of Desorption	kJ/mol CO_2	35-38	35-38
Proposed Module Design		*(for equipment developers)*	
Flow Arrangement/Operation	—	Rapid cycle rotary valves moving beds	
Flue Gas Flowrate	kg/hr	—	
CO_2 Recovery, Purity, and Pressure	% / % / bar	90-95 95	150

Definitions:

STP – Standard Temperature and Pressure (15°C, 1 atm).

Sorbent – Adsorbate-free (i.e., CO_2-free) and dry material as used in adsorption/desorption cycle.

Manufacturing Cost for Sorbent – "Current" is market price of material, if applicable; "Target" is estimated manufacturing cost for new materials, or the estimated cost of bulk manufacturing for existing materials.

Adsorption – The conditions of interest for adsorption are those that prevail at maximum sorbent loading, These may be assumed to be 1 atm total flue-gas pressure (corresponding to a CO_2 partial pressure of 0.13 bar) and 40°C.

Desorption – The conditions of interest for desorption are those that prevail at minimum sorbent loading. Operating pressure and temperature for the desorber/stripper are process dependent.

Pressure – The pressure of CO_2 in equilibrium with the sorbent. If the vapor phase is pure CO_2, this is the total pressure; if it is a mixture of gases, this is the partial pressure of CO_2.

Packing Density – Ratio of the laminated sorbent composite sheet area/filter bed volume.

Equilibrium Loading – The basis for CO_2 loading is mass of dry sorbent measured with 20% CO_2 in nitrogen (N_2) mixture without moisture.

Flow Arrangement/Operation – Gas-solid module designs include fixed, fluidized, and moving bed, which result in either continuous, cyclic, or semi-regenerative operation.

Estimated Cost – Basis is kg/hr of CO_2 in CO_2-rich product gas, assuming targets are met.

Other Parameter Descriptions:

Chemical/Physical Sorbent Mechanism – Physisorption.

Sorbent Contaminant Resistance – High oxidation resistance below 50 parts per million (ppm) sulfur oxide (SO_X) and nitrogen oxide (NO_X).

Sorbent Attrition and Thermal/Hydrothermal Stability – Very stable under direct steam regeneration.

Flue Gas Pretreatment Requirements – Conventional direct contact cooler (DCC). Chemical scrubber to decrease contaminants and particulates (SO_X less than 10 ppm; nitrogen dioxide [NO_2] less than 10 ppm; dust less than 20 mg/Nm^3).

Sorbent Make-Up Requirements – Five-year lifetime without bed replacement.

Waste Streams Generated – No chemicals in depleted N_2 and typical cooling water blow-down.

TABLE 2: CARBON CAPTURE ECONOMICS

Economic Values	Units	Current R&D Value	Target R&D Value
Cost of Carbon Captured	\$/tonne CO_2	50	30
Cost of Carbon Avoided	\$/tonne CO_2	Site-specific	Site-specific
Capital Expenditures	\$/TPD	70,000-80,000	60,000-70,000
Operating Expenditures	\$/tonnes CO_2	26-28	20-23
Cost of Electricity	\$/tonnes CO_2	12-18	12-18

Definitions:

Cost of Carbon Captured – Projected cost of capture per mass of CO_2 captured under expected operating conditions.

Cost of Carbon Avoided – Projected cost of capture per mass of CO_2 avoided is site specific depending on the source of electricity and steam.

Capital Expenditures – Projected capital expenditures in dollars per tonne per day of capacity.

Operating Expenditures – Projected operating expenditures in dollars per unit of tonne of CO_2 produced, including filter bed replacement and compression cost.

Cost of Electricity – Projected cost of electricity per unit of tonne of CO_2 produced for a range of price of electricity of 3.5–6 cents per kilowatt-hour (kWh).

Scale of Validation of Technology Used in TEA – The technology numbers were validated for use in the techno-economic analysis (TEA) from pilot-scale data.

technology advantages

- Svante's technology has the potential to enable a 50% reduction in capital costs of the capture unit compared to first-generation approaches.
- Novel technology replaces large chemical solvent towers (conventional approach) with a single piece of compact equipment, significantly reducing capital expenses (CAPEX).
- Usage of ultra-stable solid sorbent prevent toxic emission.
- Advanced sorbent material exhibits sharper temperature and pressure swing absorption and desorption, which allows for lower energy loads and faster kinetic rates.
- The proprietary material also exhibits unique resistance to SO_X and NO_X, oxygen impurities, and moisture swings.
- Svante unique laminate technology unlocks to use of different sorbents for performance or lifetime optimization (segmented bed concept).

R&D challenges

Tuning the two sorbents—materials, coatings, and manufacturing—to work in synergy within the same process conditions.

status

The project team successfully built a dual-channel parallel film heat exchanger with adsorbent and an extremely low mass flow separator (bi-layered concept). They demonstrated the effectiveness of heat transport between the A and B sides. The project team also demonstrated fast indirect regeneration of sorbent across the barrier layer and found a significant reduction (~35%) in the steam ratio by avoiding excess steam addition. However, the increase in complexity of the manufacturing of the bi-layered beds combined with the required modification of the actual RAM is a drawback. The use of the segmented bed concept optimizing the lifetime or regeneration energy of a bed by the optimization of the sorbent choice for the local condition in a Svante bed is a highly promising Mark II design. The target KPIs at the VTS level were clearly identified for both low- and high-CO_2 concentration segmented bed concept. The Electricore team will start long-term testing using the VeloxoTherm RAM field demonstration unit. Svante was able to scale-up MOF manufacturing to the tonnes scale with the help of the BASF chemical company.

available reports/technical papers/presentations

Jelen, D and Hovington, P. "Advanced Structured Adsorbent Architectures for Transformative CO_2 Capture Performance," 2021 NETL Carbon Management Research Project Review Meeting, Pittsburgh, PA, August 2021. *https://netl.doe.gov/sites/default/files/netl-file/21CMOG_PSC_Jelen.pdf*.

Jelen, D and Cizeron, J. "Advanced Structured Adsorbent Architectures for Transformative CO_2 Capture Performance," 2020 NETL Project Review Meeting - Carbon Capture, Pittsburgh, PA, October 2020. *https://netl.doe.gov/sites/default/files/netl-file/20VPRCC_Jelen.pdf*.

Jelen, D. "Advanced Structured Adsorbent Architectures for Transformative CO_2 Capture Performance," Budget Period 1 Review Meeting, Pittsburgh, PA, June 2020. *https://netl.doe.gov/projects/plp-download.aspx?id=10743&filename=Advanced+Structured+Adsorbent+Architectures+for+Transformative+CO2+Capture+Performance.pdf*.

Jelen, D. "Advanced Structured Adsorbent Architectures for Transformative CO_2 Capture Performance," 2019 NETL CO_2 Capture Technology Project Review Meeting, Pittsburgh, PA, August 2019. *https://netl.doe.gov/sites/default/files/netl-file/D-Jelen-Electricore-Adsorbent-Architectures.pdf*.

Jelen, D. "Advanced Structured Adsorbent Architectures for Transformative CO_2 Capture Performance," Kickoff Presentation, Pittsburgh, PA, August 2019. *https://netl.doe.gov/projects/plp-download.aspx?id=10744&filename=Advanced+Structured+Adsorbent+Architectures+for+Transformative+CO2+Capture+Performance.pdf*.