Demonstration of a Continuous-Motion Direct Air Capture System

primary project goal

Global Thermostat LLC (Global), in partnership with Zero Carbon Partners, VADA LLC, Georgia Institute of Technology, and the National Renewable Energy Lab, will develop a continuous motion direct air capture (DAC) system that will capture carbon dioxide (CO_2) from the air through an adsorption process and produce a greater than 95% purity CO_2 product. The process employs honeycomb monolith contactors with a solid amine sorbent incorporated into the pores of the monolith, resulting in high CO_2 adsorption capacities at very low CO_2 partial pressures. The project team is designing and validating the mechanical components of the system and completing detailed engineering and sizing of the process equipment. In parallel, a phenomenological flow model and a systems-level Aspen model is being developed to refine process step development, monolith lifetime, and key performance tradeoffs. Global is leveraging the phenomenological model to inform experimental work while assessing the impacts on sorbent lifetime. The process equipment is being fabricated, delivered, and integrated with the mechanical system to form an integrated DAC system. The prototype DAC unit will be commissioned and operated at the Global Thermostat Technology Center to collect onstream data that will inform the techno-economic and life cycle analyses (TEAs and LCAs).

technical goals

- Develop the mechanical component and process equipment prototype engineering design.
- Develop a phenomenological flow model and a systems-level Aspen model that will refine process step development, estimate monolith lifetime, and key performance tradeoffs. Validation of models from experimental data will be used to supplement the basic engineering design for component capital expenditure (CAPEX) estimation and scaling analysis.
- Perform initial TEA and LCA to evaluate purge-step tradeoffs, cost sensitivity to key parameters, and scale-up versus scale-out cost projections.
- Generate operational data from the DAC prototype, including a prolonged period of continuous operation, to feed into and refine the Aspen model to inform the prescreening TEA and LCA deliverables.
- Following the process conditions optimization, the unit will be operated continuously for one month to collect onstream data and demonstrate operability and reliability.

technical content

A primary challenge for DAC is low-cost, high-efficiency air contact. The Global DAC process employs relatively shallow honeycomb monolith contactors (~15 cm deep) that permit low pressure drops (100s of Pa) at gas approach velocities of 3–5 meters per second (m s^{-1}) while still maintaining a high geometric surface area per unit volume (Figure 1). This approach minimizes costs for gas processing by allowing the use of draft fans for gas movement upstream of the capture process.

program area:
Carbon Dioxide Removal

ending scale:
Bench Scale

application:
Direct Air Capture

key technology:
Sorbents

project focus:
Honeycomb Contactor with Amine-Based Sorbent for DAC

participant:
Global Thermostat LLC

project number:
FE0031957

predecessor projects:
N/A

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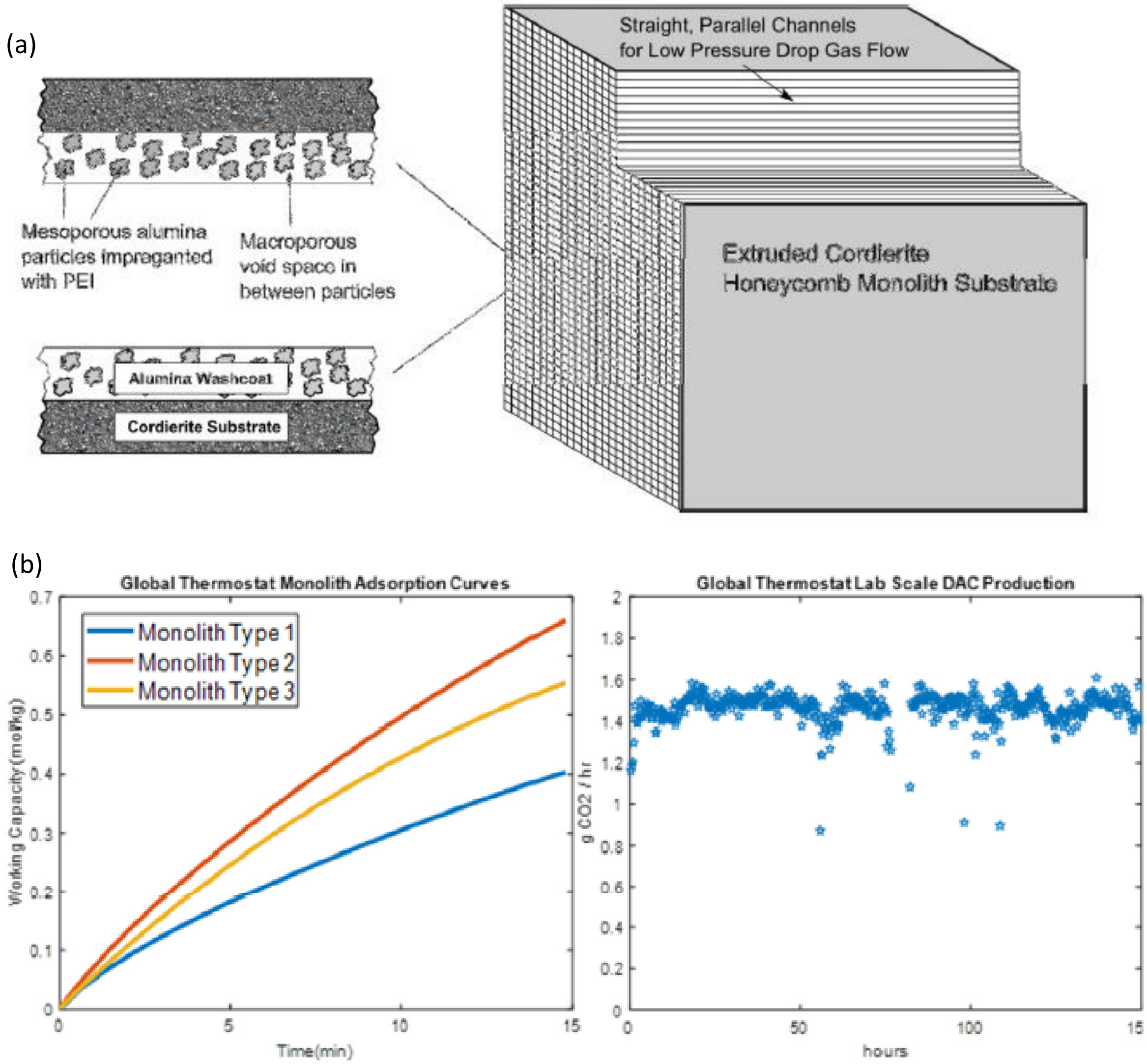

Figure 1: (a) Schematic of monolith used in the Global process; (b) 15-minute DAC working capacities for Global monoliths developed.

Monolith contactors are already made on a commercial scale for numerous applications, and the technology to wash coat them with porous oxide films is mature. Global has active Joint Development Agreements (JDAs) with three global monolith manufacturers that have resulted in several production generations of advanced DAC material technology. The adsorbent itself is critical to the efficacy of the process, as it sets the productivity levels and regeneration requirements. Global has worked with Georgia Tech for several years on sorbents specifically designed for DAC. The current sorbent material is low molecular weight (~800 Dalton), highly branched poly(ethyleneimine) (PEI) that is incorporated into pores within a monolith. This allows for high volumetric amine loadings (i.e., amine sites/adsorbent volume). Solid amine adsorbents interact with CO_2 via a chemisorptive mechanism, resulting in high CO_2 adsorption capacities at very low CO_2 partial pressures and high selectivity to CO_2 over other components in air, including water. It is well established that the presence of humidity in air improves the efficiency of the adsorbent. Working capacities up to approximately 0.65 mol CO_2 per kg sorbent have been demonstrated under the standard Global adsorption process conditions of 5 m s^{-1} air approach velocity and a 15-minute duration (Figure 1b).

A drawback of the current PEI sorbent is a limited lifetime, primarily due to oxidation and polymer leaching. Global has done extensive prior research in both of these areas to establish lifetime targets. Figure 1b shows cyclic onstream data at laboratory scale for approximately 150 continuous hours of operation. PEI leaching rates and oxidation rates have been measured and it is estimated that the sorbent can maintain 80% of its capacity over approximately 100,000 cycles.

Desorption of CO_2 is performed by a temperature swing delivered by condensation of saturated steam directly onto the monolith surface, raising the temperature to approximately 70–100°C. Steps are performed before and after this to maintain sorbent lifetime and achieve high CO_2 purity. The core sequence of the Global regeneration process cycle is as follows:

1. Reduction in O_2 concentration surrounding the monolith.
2. Direct contact condensation of steam to heat the monolith and desorb CO_2.
3. Cooling of the monolith by evaporation of condensed water on its surface.

Internal heat integration may be performed by recycling the stream, resulting from Step 3 and including it in Step 1. In the current first-generation Global batch process, Step 1 and Step 3 are performed using vacuum. In the second-generation continuous process described here, these steps are performed with inert gas or a recycled product CO_2 stream. Critically, CO_2 is being neither adsorbed nor desorbed in Step 1 or Step 3, so minimizing their cumulative step times is important for maximizing productivity. Step 3 is conducted at constant pressure and CO_2 is removed as it is evolved by a vacuum pump or blower. This approach produces a steam/CO_2 mixture that, after passing through a condenser/separator, gives a 95+% CO_2 product.

technology advantages

- Rapid cycles (less than 20 minutes) enabled by monolith contactor (adsorption) and steam regeneration (desorption); reduced amortized CAPEX.
- High capital utilization efficiency (improved CAPEX) while maintaining low pressure drop, improved operation expenses (OPEX) via panel movement.
- High uptakes enabled by amine dense sorbent (improved CAPEX and OPEX).

R&D challenges

- Physical movement of large components can be mechanically challenging, particularly in a batch process (start/stop).
- Maintaining adequate sorbent life over many cycles.
- Requires careful consideration of movement and sealing methodologies to maximize adsorbent lifetime.

status

Global Thermostat has developed computational fluid dynamics (CFD) models to understand airflow uniformity and air movement efficiency schemes. Process development Aspen Model has also been developed to understand the scalable model to evaluate costs at both large and pilot scale, utilities for steam generation and cooling water, and CO_2 compression costs. Monolith cooling has been proposed to be carried out with nitrogen instead of using vacuum and work is continuing to understand the tradeoffs with nitrogen purity and how this affects OPEX, CAPEX, sorbent lifetime, etc.

available reports/technical papers/presentations

Eric W. Ping, "Demonstration of a Continuous Motion Direct Air Capture System," Direct Air Capture Kickoff Meeting Presentation, Pittsburgh, PA, February 2021. *https://netl.doe.gov/sites/default/files/netl-file/21DAC_Ping.pdf*.

Miles Sakwa-Novak, "Demonstration of a Continuous Motion Direct Air Capture System," NETL Carbon Management Research Project Review Meeting, Pittsburgh, PA, August 2021. *https://netl.doe.gov/sites/default/files/netl-file/21CMOG_CDRR_Novak.pdf*