Electric Field Swing Adsorption for Carbon Capture Applications

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Introduction

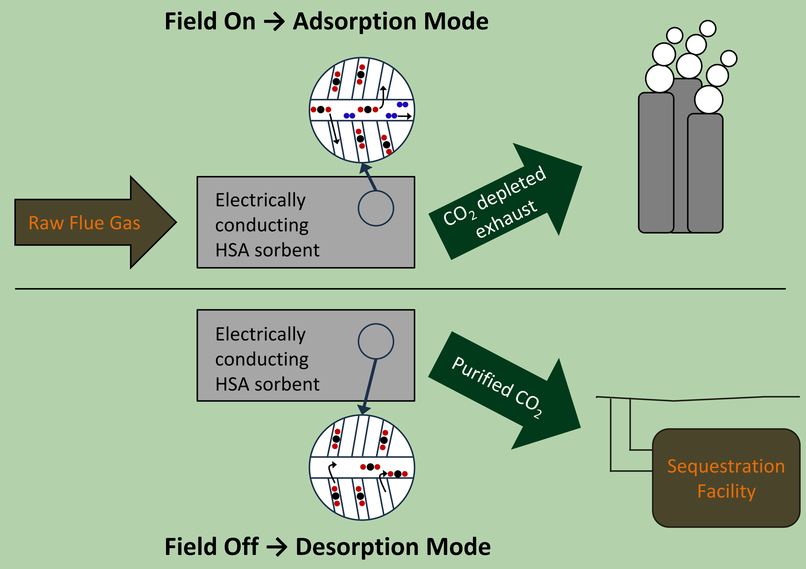
Carbon capture is essential for reducing CO_2 pollution during the transition from fossil fuels to green energy. Condensed-phase sorbent materials, capable of selectively binding CO_2, target coal fired plants and fixed point sources as a post-combustion solution. While current sequestration methods such as Pressure Swing Adsorption (PSA) and Temperature Swing Adsorption (TSA) have been developed, there is an undesirable energy cost during the desorption step. This greatly reduces power generation efficiency and is owed to the thermodynamic conditions required for CO_2 release, including low pressures and high temperatures. Electric Field Swing Adsorption (EFSA) is designed to reduce the parasitic energy load using an applied electric field to drive the cycling of CO_2 with a basic on/off switch for gas separation. Thermodynamics of adsorbent/adsorbate interactions are instantaneously modified with the external field. If successful, the process can be accomplished with stationary sorbents at ambient conditions, preventing the need for large changes in temperature, pressure, or concentration of the system. Sorbent material can be reused after releasing CO_2 with the field off, making the process inherently reversible. The reversibility of this stationary model will also decrease CO_2 capture and release cycle times, as the thermodynamics of the sorbent are changed quickly relative to existing technologies. Additionally, abrupt release of large CO_2 volumes in a small space may compress gas and begin the pressurization process needed to contain large amounts of carbon. Complete realization of EFSA to its fullest potential should increase efficiency of overall energy production, making EFSA a desirable option for carbon capture.

Key Transformative Aspects

- **Simple:** EFSA enables gas separation and capture using electric fields to change the thermodynamics of the sorbent material
- **Reversible:** Switching between ad-/desorption as simple as switching field on and off; removes need to transport or heat sorbent materials
- **Efficient:** Electrical current used during charging is partially regenerated in discharging → minimal parasitic load for EFSA-based CO_2 capture

Major Challenges

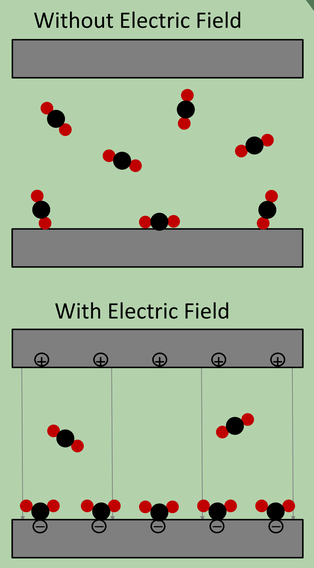
- **Magnitude of effect**: Achieving field strengths and geometries necessary to enhance molecular gas adsorption
- **Selectivity:** Achieving selectivity of CO_2 adsorption over N_2 adsorption
- **Scalability:** Can we realize this technology proof of concept in a practical way?



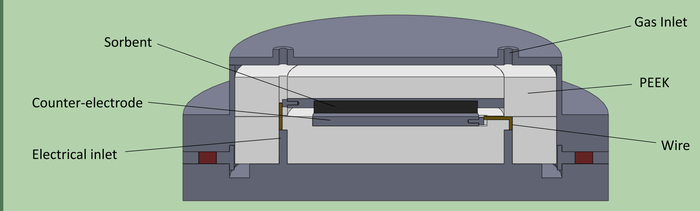
Electrolyte-free implementation of EFSA with high-fields

Concept

- High surface area (HSA) carbon (e.g. CMK, BPL) provides electrically conductive sorbent with large capacity for CO_2 capture
- Adsorption sites extend throughout networked microporous and mesoporous structure
- "Swing" adsorption techniques swing system into a state which promotes adsorption or desorption
- EFSA is unique because it changes thermodynamic properties of sorbent
- Electric field creates favored adsorption sites by pumping charges into sorbent
- Enhanced adsorption with negative charges is expected to have partial chemisorptive character
- Negative charges serve as electron donating centers on sorbent surface, driving formation of dative bonds by supplying electron density to Lewis acid center of CO_2
- Selectively adsorbs CO_2 over N_2, a major component of flue gas, due to Nitrogen lacking appreciable electron accepting center
- Linear CO_2 expected to bend upon accepting surface electron density, and should be detected by shifts in IR spectrum
- Desorption by removing field, weakening chemisorption interactions between CO_2 and carbon sorbent



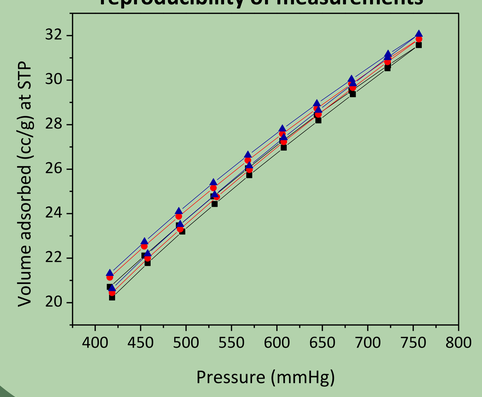
Experiment



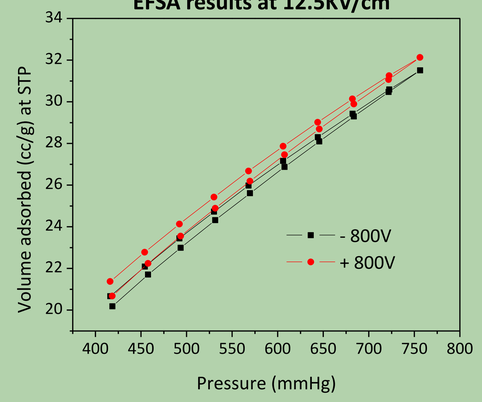
- Custom sample cell designed to accommodate electric field on sorbent during isotherm measurement
- Isolated carbon sorbent electrode and stainless steel counter-electrode, spaced by 0.64 mm gap inside vacuum-tight stainless steel pressure vessel
- PEEK filler inserted to minimize internal cell volume and Increase sensitivity

- Sorbent BPL carbon pellet (~200 mg, 13 mm diam.) pressed with 5% Nafion binder at 6-7 tons for 1-2 minutes
- Electric field effect on CO_2 adsorption capacity determined by measuring isotherms on the Autosorb 1 instrument
- Isotherms measured with electric fields of 12.5KV/cm (+/- 800V across 0.064mm) and also without field (0 V)
- Changes in adsorption isotherms with and without applied fields inconclusive → all within the ~2% instrumental precision
- Future improvements planned: use higher dielectric strength material as electrical break in order to achieve higher fields, explore different field geometries and thin film electrode structures

Multiple runs at 0V to establish reproducibility of measurements



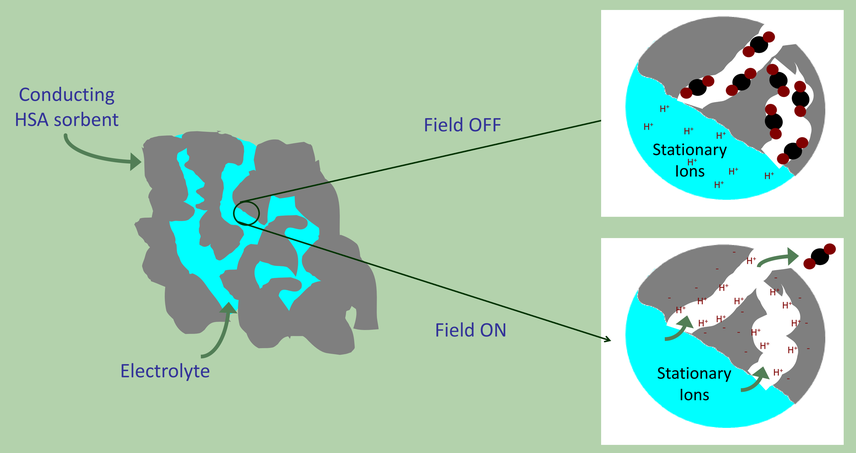
EFSA results at 12.5KV/cm



Electric Field Driven Ion Sweeping (EFDIS)

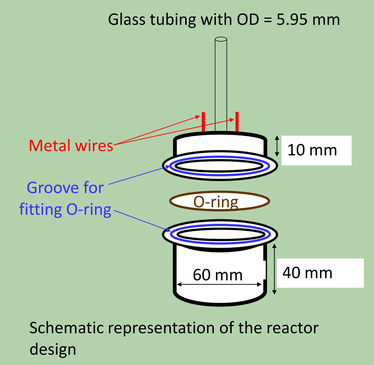
Concept

- High-capacitance (100 F/g) solid state capacitors based-on electric double-layer capacitors (EDLCs) have been demonstrated previously.[1,2]
- EFDIS utilizes EDLC approach to reversibly alter the chemical nature of pore surfaces to change affinities of gases for HSA sorbent materials
- Employ size mis-match between ions in electrolyte: use small ions (e.g. H^+) as mobile phase, paired with large counter-ions such as Nafion polymer or ionic liquid as "stationary" phase
- Stationary phase confined to interparticulate space and/or mesopores, leaving micropore surfaces free for CO_2 adsorption in absence of applied field
- When field is switched on, conducting sorbent acquires surface charge, drawing in mobile phase ions to dynamically change surface properties of sorbent materials.
- Cycling between charged and discharged states affords rapid switching between adsorption and desorption modes.



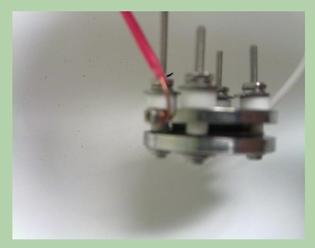
Design and Fabrication of Test System

- Glass pressure vessel designed and fabricated to measure the sorption behavior of CO_2 in an EDLC as described above
- Electrodes material was BPL carbon composite with (5-30 wt %) Nafion to achieve both proton and electrical conductivity
- Cathode and anode separated by electrically insulating Nafion membrane
- Initial tests inconclusive; check of capacitance revealed issues with electrode design
- Future work: further electrode designs/compositions currently under exploration, as are fundamental studies investigating ion mobility in micropores of conducting sorbent materials



Schematic representation of the reactor design

Fabricated reactor



Electrode set up

Selected references

1. P. Staiti, M. Minutoli, and F. Lufrano, Electrochimica Acta **47** (2002) 2795.
2. P. Staiti and F. Lufrano, Electrochimica Acta **53** (2007) 710.