Novel Sorbent Platforms for Moisture Swing Carbon Capture

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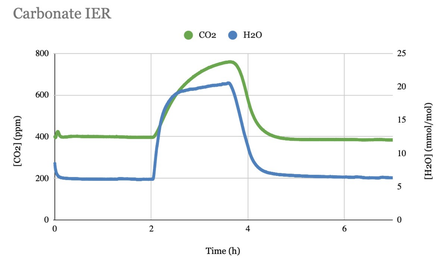
Abstract

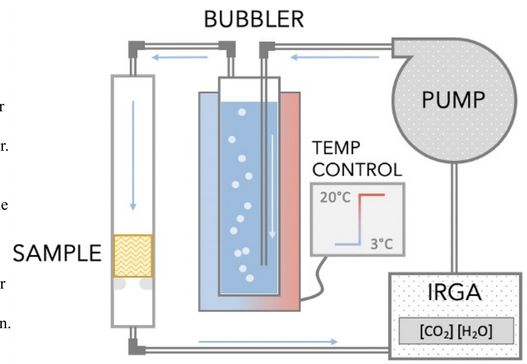
This project sought to discover new materials for use in direct air carbon capture, leveraging the "moisture-swing" effect, where engineered materials release carbon under wet conditions and capture carbon under dry conditions. Our purpose was to characterize and understand this effect in an expanded library of anion exchange resins and anion-coated nanomaterial sorbents. Carbon capture is essential for reversing the effects of climate change, through the removal of greenhouse gases from the atmosphere. Immediate implications include expanding the toolset available to carbon capture researchers and gaining insight into gas separations and the adsorption of carbon dioxide. Current research show four new ions exchanged into ion exchange resin capture carbon at around the same magnitude as the two ions already discovered in the literature: carbonate and phosphate. The new ions, pyrophosphate, tripolyphosphate, borate, and orthosilicate, demonstrated promising results as lower cost materials while sacrificing the magnitude of the moisture-swing effect on a per mass basis. It is of interest to optimize the thermodynamics and kinetics of these sorbent materials to optimize the "moisture-swing" effect while developing more efficient and sustainable methods of removing carbon from the atmosphere. Further research will seek to optimize the methodology of nano-structured graphite and other materials as sorbents through more effective materials synthesis, more creative engineered setups, and testing other possible ions for carbon capture.

Background & Approach

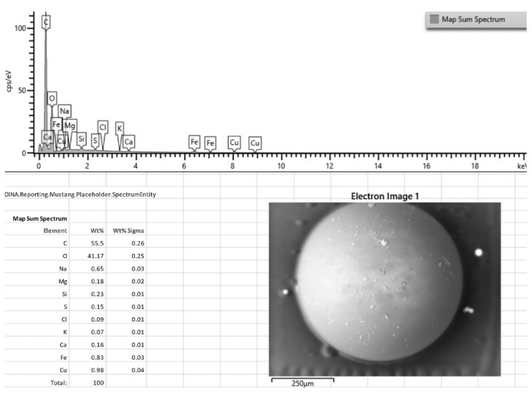


The general chemical mechanism of the capture of carbon through a humidity swing can be described by four main transition states. A typical moisture swing is shown to the left with the carbon dioxide and water curve. The empty-fresh phase is when the sorbent is loaded into the sample holder in dry condition. H2O splits into H+ and OH− ions during from Empty-fresh to Empty-Dry transition. Bicarbonate ions form during this OH− formation transition. Absorption describes the transition between Empty-Dry and Full-Dry when CO2 is fully absorbed into the sorbent in dry conditions (0 to 2 hours on figure) due to the high affinity of CO2 to hydroxide ions. The desorption phase transitions the sample into an Empty-Wet state through addition of humidity where the regenerating sorbent releases CO2 into the system due to the bicarbonate ion reaching its full hydration state (2 to 3.5 hours on figure).

The methodology by which the carbon capture of various sorbents was explored began with the system designed to measure the absorption and desorption of CO_2 for each sample while also measuring the water. The system was engineered prior to the beginning of the project. It allowed for a sample to be secured within a looping system which began in an open state to take in ambient air. Once the system equilibrated with the ambient environment, the loop was closed, and the pump was turned on to circulate air flow. A portion of the closed circuit allowed for the temperature of a bubbler to be altered to vary the humidity of the system. An Infrared Gas Analyzer (IRGA) in the loop setup detects both CO_2 and H_2O, allowing for the quantification of humidity and changes in carbon concentration during each experimental run.

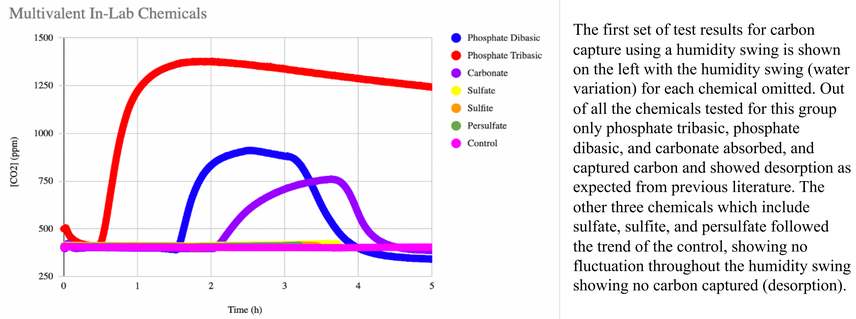


Ion-Exchange Confirmation (SEM & EDS)



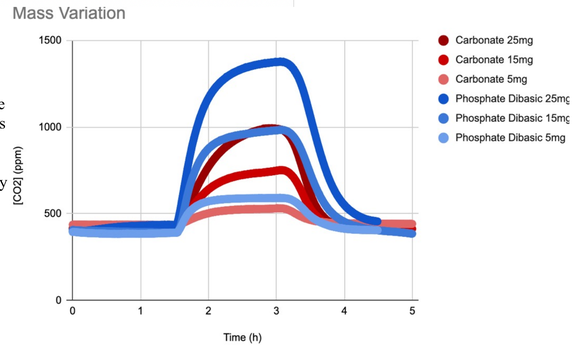
The images shown to thee left show the EDS data for an ion exchange resin bead which was exchanged with borate ions. Using these images EDS was performed to confirm the presence of borate ions. This was difficult to identify due to the boron and carbon peaks on EDS being very close to each other. Although, the limited presence of chloride ions were confirmed which the borate ions would be exchanged for. This was a partial confirmation for this ion-exchange resin. Multiple other resin beads exchanged with different ionic solutions were confirmed with EDS.

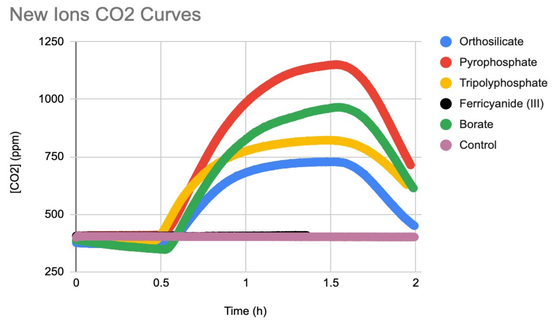
Moisture Swing Results



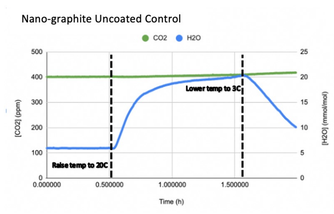
The first set of test results for carbon capture using a humidity swing is shown on the left with the humidity swing (water variation) for each chemical omitted. Out of all the chemicals tested for this group only phosphate tribasic, phosphate dibasic, and carbonate absorbed, and captured carbon and showed desorption as expected from previous literature. The other three chemicals which include sulfate, sulfite, and persulfate followed the trend of the control, showing no fluctuation throughout the humidity swing showing no carbon captured (desorption).

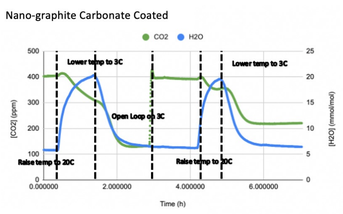
The results regarding the carbon capture with differing masses of the ion exchange resin samples is shown to the right. It was expected that if the mass of the sorbent was doubled, the carbon captured would double as well. The trend was affirmed by these results showing that the amount of carbon captured was proportional with increasing mass of the sample. This was an important distinction to confirm that the system was calibrated and adjusted properly.

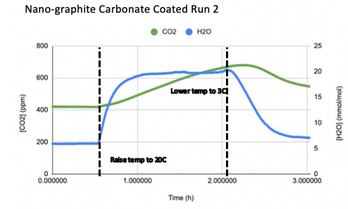


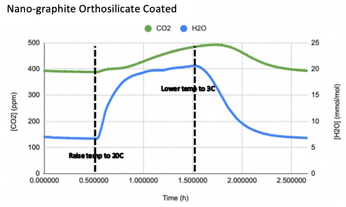


The second set of ions are shown to the left. The first novel successes of the project were shown here with pyrophosphate, tripolyphosphate, borate, and orthosilicate all capturing similar amounts of carbon as phosphate and carbonate which were previously shown above. Differing masses were used for most of these samples, so it was important to also demonstrate the carbon capture performance on a per mass basis in further figures. The importance in these results lies in the discovery of four new ions that, once loaded into an ion exchange resin, capture carbon equally as well if not better than the previously known two ions. This finding single- handedly triples the toolbox of ions for the moisture-swing carbon capture community.

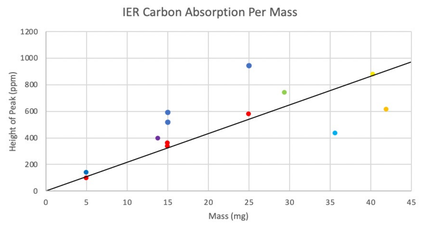






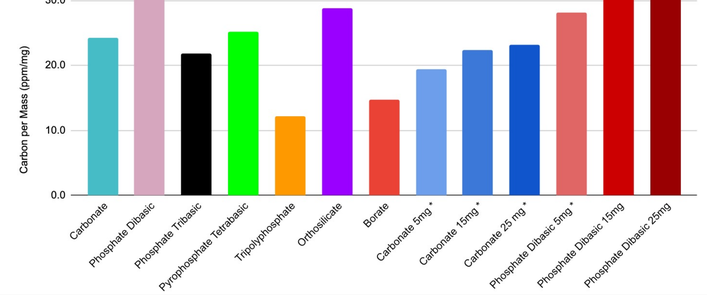


Conclusions

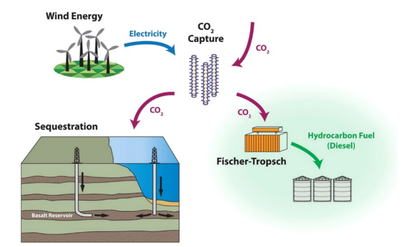


IER Carbon Absorption Per Mass	Mass (mg)	Height of Peak (ppm)	Carbon per Mass (ppm/mg)
Carbonate	15	363	24.2
Phosphate Dibasic	15	518	34.6
Phosphate Tribasic	40.3	879	21.8
Pyrophosphate Tetrabasic	29.4	741	25.2
Tripolyphosphate	35.6	435	12.2
Orthosilicate	13.8	398	28.8
Borate	41.9	616	14.7
Carbonate 5mg	5	97	19.4
Carbonate 15mg	15	336	22.4
Carbonate 25 mg	25	579	23.1
Phosphate Dibasic 5mg	5	141	28.2
Phosphate Dibasic 15mg	15	593	39.6
Phosphate Dibasic 25mg	25	944	37.7

The analysis of humidity swing carbon capture through various sorbent platforms proved to be useful in deter- mining many new ions coated on ion-exchange resin and nano-structured graphite which could capture carbon. The new ions found to successfully do so included: pyrophosphate, tripolyphosphate, orthosilicate, and borate. These ions have associated chemical mechanisms which follow the general carbon capture mechanism to model their success. Nano-structured graphite proved to be a useful sorbent platform which can be coated in newly discovered carbon capture ions or previously used ions such as carbonate or phosphate to capture carbon. Amid the newly discovered ions, none have been shown to capture more carbon per mass of sample than phosphate dibasic and phosphate tribasic, although orthosilicate has shown to surpass carbonate. Some ions that did not work when exchanged onto IER included sulfate, persulfate, sulfite, and ferricyanide. Overall, there are many more avenues of research to take with these results to optimize the system, the surface area of nano material samples, and other ions to test for greater carbon uptake than the now tripled library of ions that do so.



Future Work



- Switching between wet and dry air feeds
- Submerging sorbents directly in water
- Using hydrophilic or hydrophobic membranes which the sorbents are loaded into to improve kinetics
- Different Containers to be able to submerge sample and perform other tests
- Performing further field testing such as altering magnetic field

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