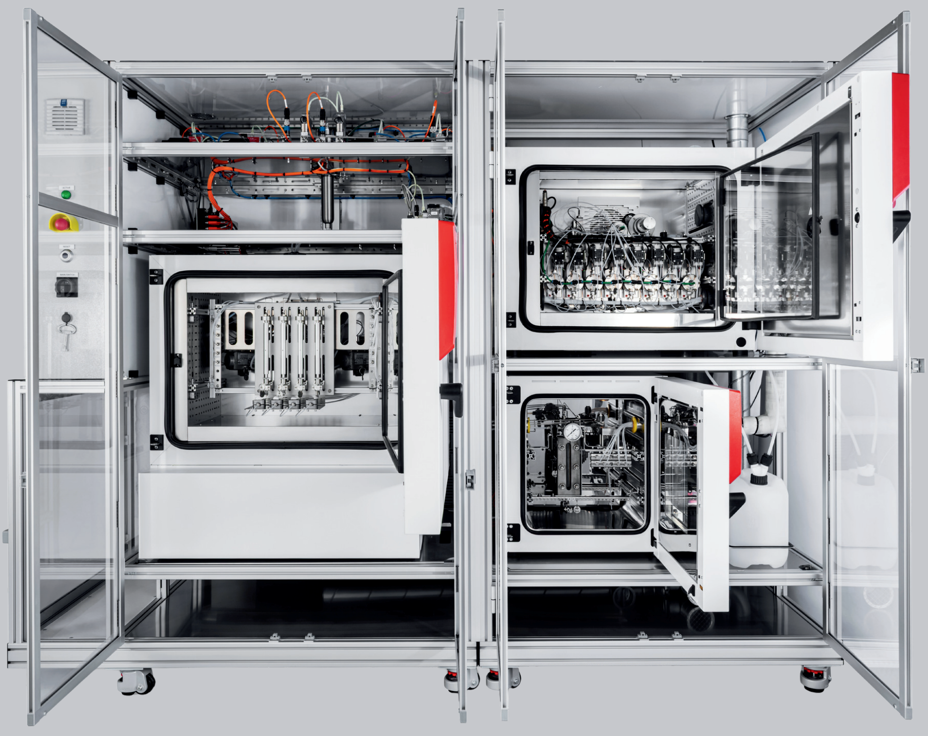
avantium

Direct Air Capture Solutions

HIGH-THROUGHPUT BREAKTHROUGH ANALYZER UNIT

Accurate, reliable and flexible multi-parallel column systems



We Are Avantium R&D Solutions

With over 25 years of experience, Avantium R&D Solutions is the leading provider of advanced catalyst and adsorbent testing units and services. Our high-throughput technology accelerates research in catalyst R&D, (ad)sorbent development, and non-volatile liquid-phase adsorption applications, enabling parallel screening of numerous adsorbents and process conditions.

Your Testing Challenges

Direct Air Capture (DAC) is vital for reducing CO_2 and combating global warming. Developing cost-effective DAC systems involves creating advanced sorbent materials with high adsorption capacity, fast rates, low energy requirements, and good recyclability. Ensuring their durability and managing costs are crucial. Efficient gas-solid contactors with minimal pressure drops are key for low-cost systems. Optimizing the adsorption and regeneration process requires understanding various parameters like kinetics, temperature, humidity, and hydrodynamics. Precise control during testing is essential for reliable data and assessing performance.

Helping DAC Technology Developers to Reduce Their Cost

Overcoming DAC R&D challenges requires sophisticated testing capabilities, and our high-throughput technology accelerates adsorbent development with precise control and simultaneous experiments under varied conditions. Real-time data from online breakthrough curves, automated 24/7 operation, and extensive data collection on adsorption/desorption cycles are significant advantages. Our systems decouple hydrodynamics from adsorption kinetics, explore different conditions, and reduce time-to-market and development costs. Integrating our experience and learning, our solutions support efficient testing and cost reduction.

Testimonials

"This agreement enables us to take a significant step forward in building out a testing environment of industrial quality and expanding our high-quality supplier ecosystem. Avantium's high-throughput adsorption testing unit will enhance our ability to develop and test new materials and accelerate the deployment of our DAC systems on a global scale."

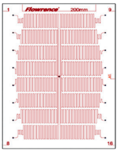
Jan Wurzbacher, Co-CEO and co-founder of **Climeworks**

"This collaboration with Avantium R&D Solutions has been highly valuable in advancing our DAC technology. The precision and efficiency of their testing system have provided us with critical data to refine our materials and improve our carbon capture solutions."

Jack Shield, Senior Scientist of **Origen Carbon**

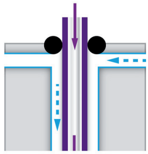
We serve a portfolio of global clients

Automated Direct Air Capture



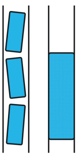
Microfluidics Distribution

- Proprietary glass chip capable of handling up to 16 columns
- 0.5% RSD (Relative Standard Deviation)
- Flow rate range 25-500 NmL/min
- Exceptional repeatability



Columns

- 1, 4, 8, up to 16 parallel columns
- User-friendly mounting
- Available in stainless steel or quartz
- Temperature range: -20 °C to 150°C (accuracy of +/- 0.1 °C)



Pretreatment

- Temperature up to 300°C
- Dry air or nitrogen, or humidified air

Materials

- Testing materials in various forms
- Shaped or structured materials
- Powders or pellets

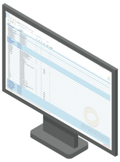
Testing Unit Features

Adsorption

- Measure capacity & selectivity
- Relative humidity 0.5-95% (SD < 1% RH)
- Fast heating (35 °C/min)
- CO_2 concentration 350 ppm to 40%

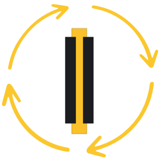
Desorption

- Temperature: 80-150 °C
- Pressure: Atmospheric—0.2–5 bar
- Active fast cooling (26 °C/min)
- TSA, Vacuum, Steam, and MSA



FlowPro Software

- Software purposely built for high-throughput systems.
- Full integration of online and offline data, with robust support for AI and machine learning integration



Extended Cyclic Performance

- Long-term testing
- 500-5000 cycles

Advantages of Avantium's high-throughput technology

Highest data quality

Reproducible results with accurate microfluidics distribution

Unmatched accuracy

Testing multiple samples simultaneously under identical test conditions

Proven applications

Proven high-throughput technology broadly used with multiple applications thanks to decades of R&D

Validated by customers

Avantium's technology extensively used by leading DAC technology developers and research institutes to accelerate their R&D

Fast screening

Process optimization or adsorbent development at reduced time to market due to simultaneous testing of multiple samples

Lower costs

Reduced time-to-market with high-throughput testing for process optimization and screening

Safe to operate

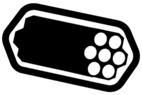
Inherently safe small-scale columns technology with minimal chemicals. Easy to operate <1 FTE required

Small footprint

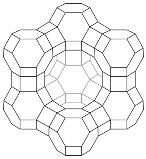
Smallest footprint in the market with low infrastructure costs. Increase the number of columns in your lab with minimal space required

Selection of **Materials** can be Tested

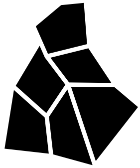
Substance



AMINE FUNCTIONALIZED RESIN

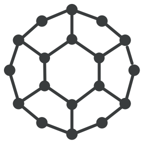


ZEOLITES

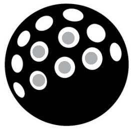


ACTIVATED CARBON

POROUS ALUMINAS

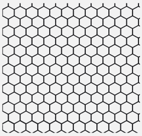


METAL-ORGANIC FRAMEWORK



SILICAS

Shape



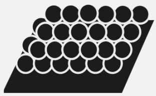
MONOLITHS

COUPONS

POWDERS

FIBERS

PELLETS



COATED MEMBERANES

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Case Study

Accelerating DAC by using high-throughput tools: The effect of particle size and humidity on the performance and stability of amine-functionalized resins in DAC

Particle size effect

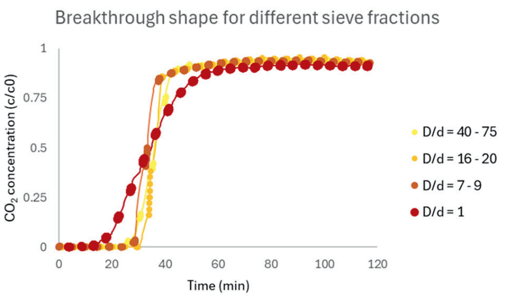
While the shape of the breakthrough curve depends on the particle size, the capacity after full breakthrough is independent on the particle size

Moisture dependence

- CO_2 slip can occur when the adsorption bed is shorter than the mass transfer zone.
- When moisture and CO_2 are co-fed to a dry adsorbent, the mass transfer zone could be extended.
- Pretreatment of the adsorbent with humid nitrogen prior to exposure to CO_2 can mitigate this effect.
- Similarly, desorption with a controlled humidity could obtain the same effect.
- Humidity during the adsorption step can play a favorable or detrimental effect on the capacity, with the capacity at 90% RH being up to twice as high as compared to capacities obtained under dry conditions.

Stability

Long-term stability testing of a set of three amine-functionalized resins shows a line-in for several cycles where a relatively sharp decrease in capacity is observed, followed by a subsequent steady deactivation over several days.



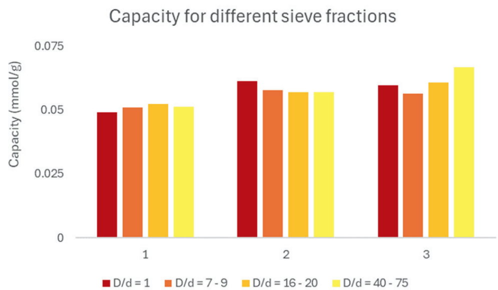


Figure 1 and 2: breakthrough curve of different breakthrough curves for a 13x zeolite material. Smaller particles give a sharper breakthrough curve (left). For these different particle sizes there is no significant effect on the capacity (right), as the column-to-column differences are larger than the differences between particle sizes.

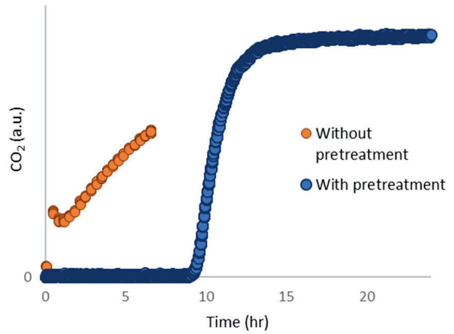


Figure 3 : When desorption is preformed with dry nitrogen there is a change that competitive adsorption between moisture and CO_2 creates a CO_2 slip upon exposure to humid challenger gas

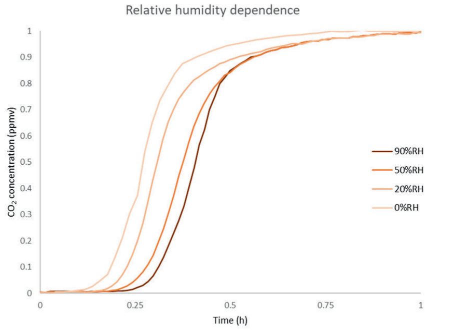


Figure 4 : Relative humidity may facilitate CO_2 adsorption, both in the primary adsorption mode, as in the tail of the breakthrough event

Conclusion

- Controlling the humidity during both the adsorption and desorption is important to obtaining relevant capacities.
- To be able to make meaningful conclusions about the medium- to long-term stability of these types of materials requires measuring the capacity at full breakthrough for multiple cycles.

Experimental

Drying: Resin materials dried at 90°C under nitrogen for 2 hours.
Pre-treatment: Materials exposed to humid nitrogen at 23°C.

Adsorption Cycles:

- 100 ml/min of N_2 containing 450 ppm CO_2 at 23°C.
- 0 to 90% relative humidity.

Desorption:

- Heating to 90°C at a rate of 60°C/h to fully capture the desorption event.

Monitoring: CO_2 levels monitored using an online mass spectrometer

Breakthrough Analysis of Four Adsorbent Samples

Materials

- Resins
- MOF
- Activated carbon
- Zeolites

Results

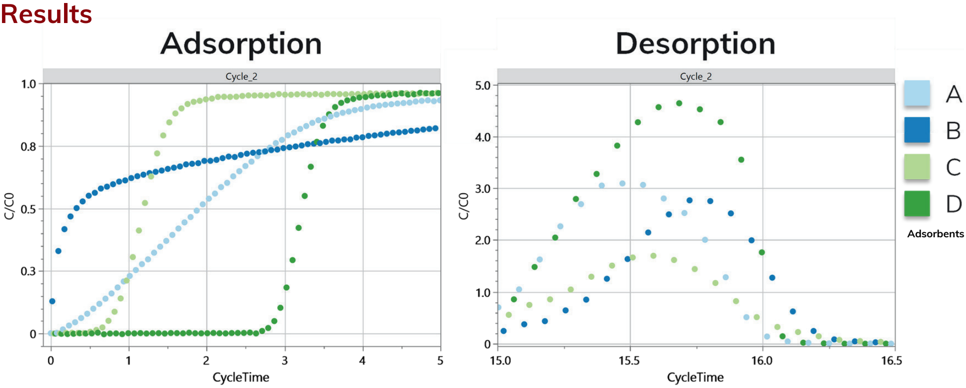


Figure 1: Breakthrough curves indicate differing adsorption behaviors due to variations in materials' chemical and physical properties, such as surface chemistry or pore size. This trend is also evident in the desorption curves.

Experimental

Drying at 90 °C under nitrogen for 2 hours

1. Pre-treatment at 23 °C under humid nitrogen*
2. Adsorption cycles (6x):
    - Temperature: 23 °C
    - Gas flow: 100 mL/min N_2 containing 500 ppm of CO_2
    - Sample weight: ~100 mg
    - Relative humidity: 53% (15000 ppm H_2O)
3. Desorption step (6x): Heat up to 90 °C by 60°C/h

*Skipped pre-treatment in cycle 5

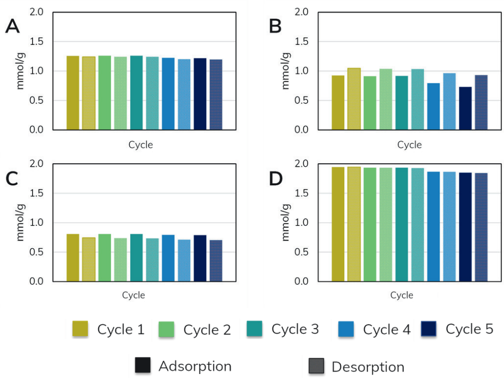


Figure 2: Comparison of adsorption capacity across cycles

Tomorrow's Chemistry Together

Overview of the whole run

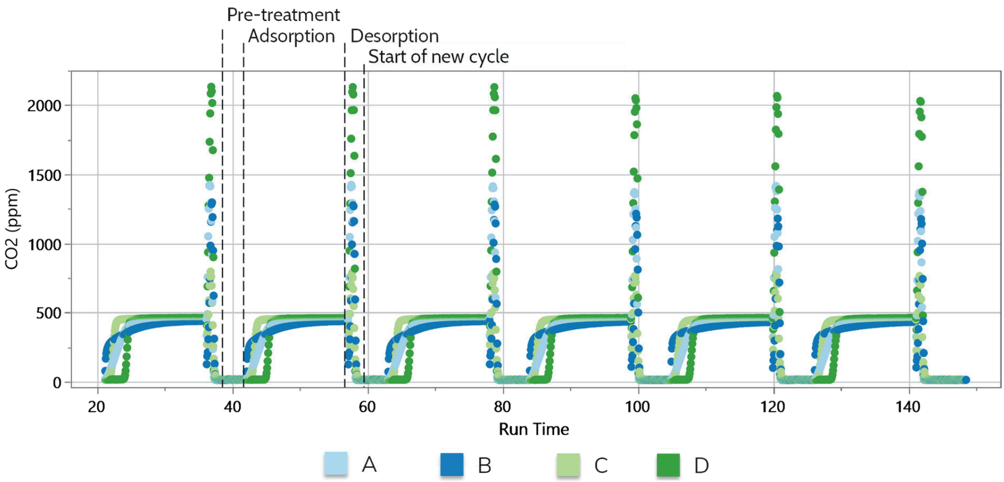
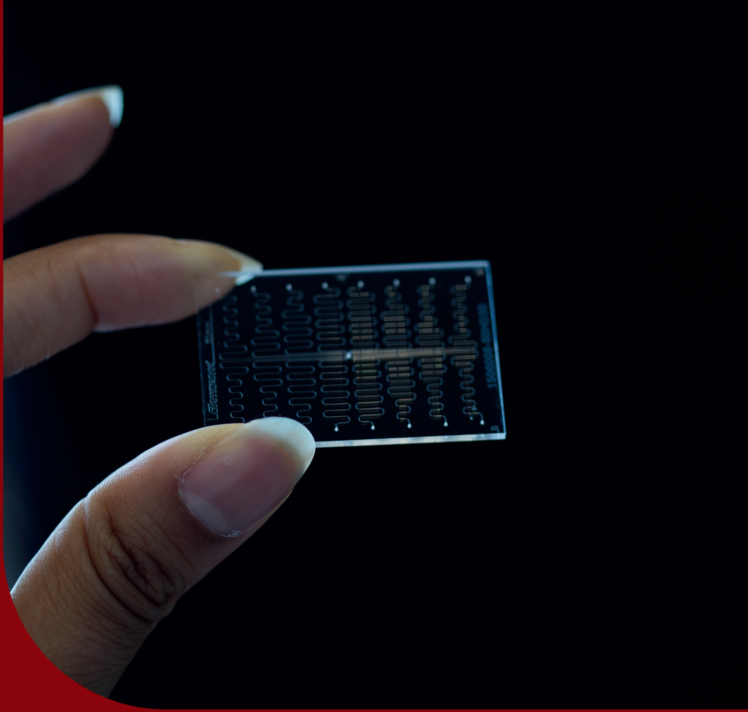


Figure 3: The six cycles of Adsorption & Desorption from the four materials

- CO_2 capacity of materials can be ordered as D > A > B > C.
- Stability of the different materials through the 6 cycles, in which the order of stability is C > A > D > B.
- The difference in adsorption and desorption. capacity for the B and C materials can be explained by the differing integration windows. Total desorption and adsorption capacities for these materials were not fully estimated.

Summary

This data shows interesting differences between four chemically and physically similar materials. These differences can be observed in the shape of the breakthrough and desorption curves, the calculated adsorption capacity and the deactivation behavior. Additionally, the data set highlights the impact of the chosen testing procedure and data processing.



Get in touch with us

rds@avantium.com

rds.avantium.com

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