Additional Developments in Atmosphere Revitalization Modeling and Simulation

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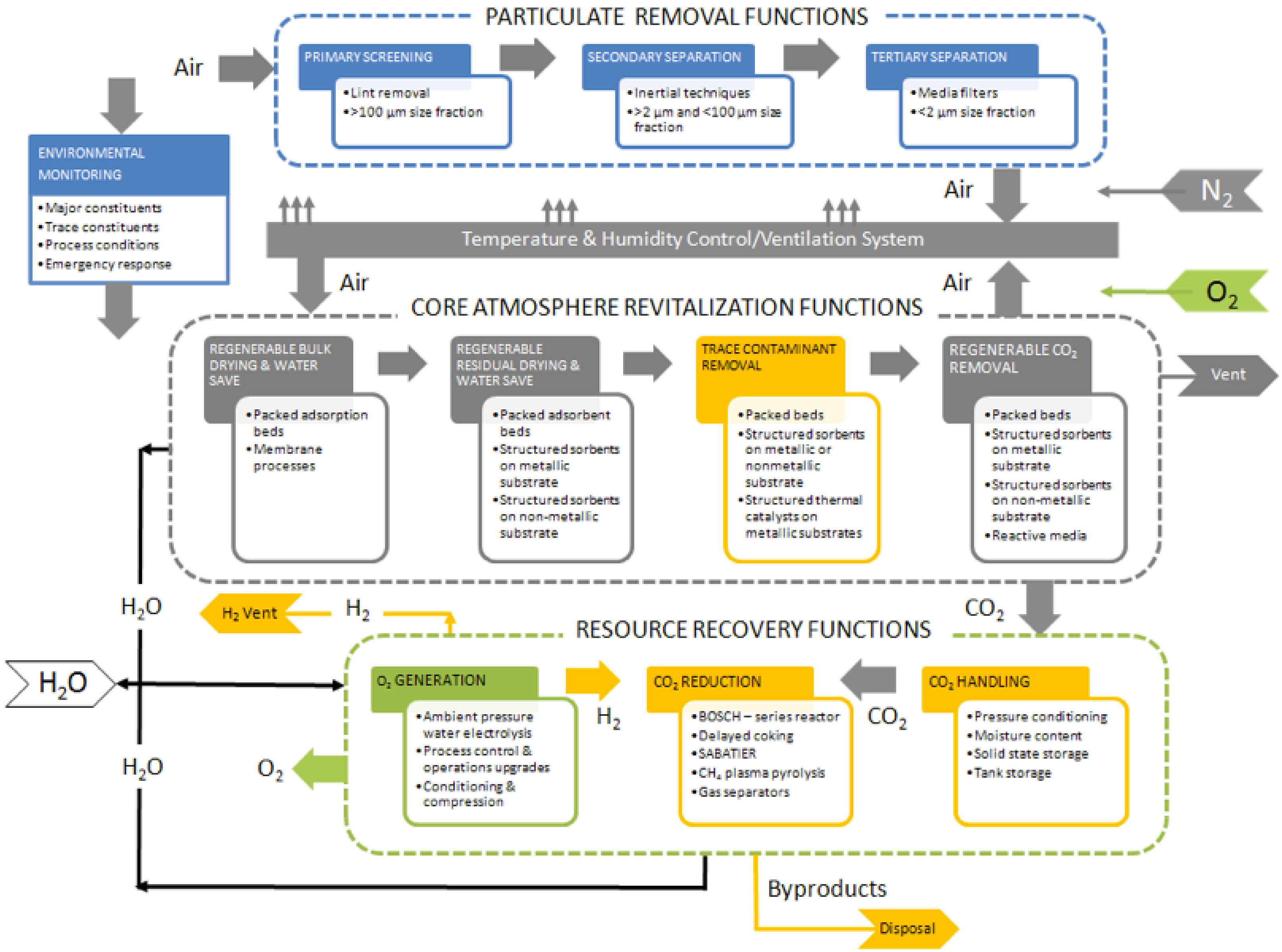
Introduction

- The Advanced Exploration Systems (AES) Program:
  - *pioneering approaches for rapidly developing prototype systems*
  - *demonstrating key capabilities*
  - *validating concepts for human missions beyond Earth orbit*
- The Atmosphere Resource Recovery and Environmental Monitoring Project (ARREM):
  - *mature integrated AR and environmental monitoring (EM) subsystems*
    - *derived directly from the ISS AR subsystem architecture*
  - *reduce developmental and mission risk*
  - *improve reliability,*
  - *lower lifecycle costs*
  - *demonstrate design and system concepts for human missions beyond Earth orbit*

ARREM System Trade Spaces



Objectives

- CO_2 Removal
- H_2O Bulk Drying
- H_2O Residual Drying

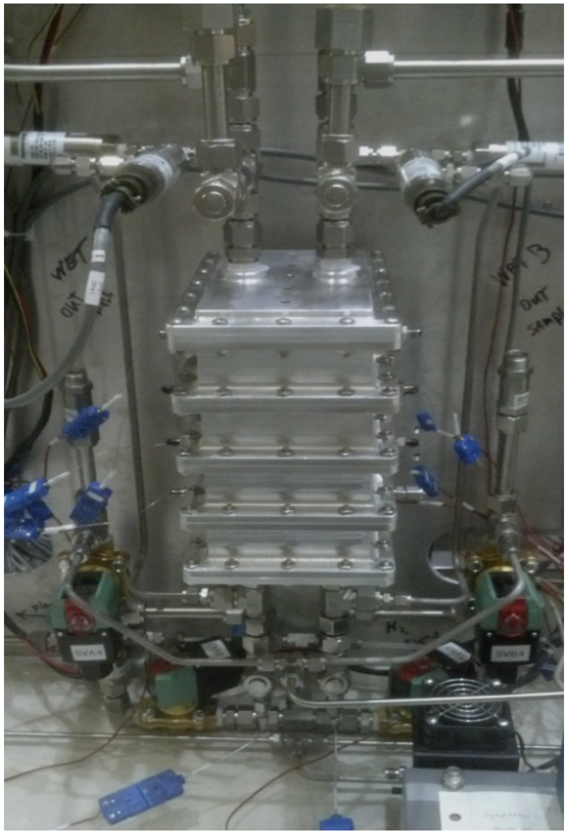
- Improve the current state-of-the-art systems utilizing fixed beds of sorbent pellets by seeking more robust pelletized sorbents
- Continue evaluations of structured sorbents for durability and efficiency (Microlith, *NovelAire*, other novel formats)
- Continue evaluations of alternate bed configurations to improve system efficiency and reliability (Isothermal Bulk Desiccant)

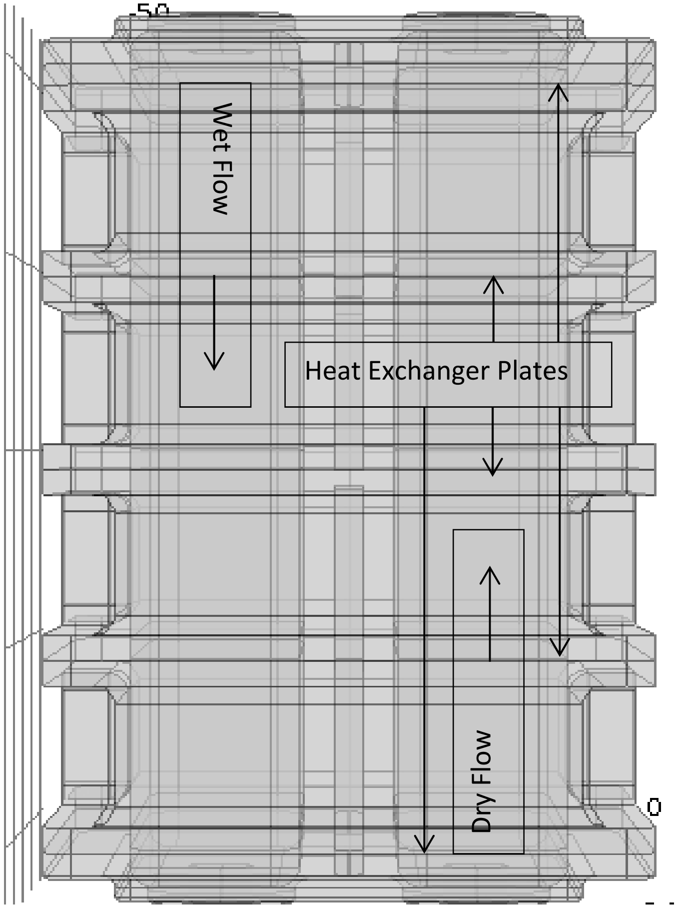
Approach

- Characterize candidate sorbents and compare directly with state-of-the-art sorbents
  - Select promising sorbent candidates for life support process of interest
- Develop new or modify existing mathematical models and computer simulations for process of interest (COMSOL)
  - Via simulation, optimize cyclic test configuration (e.g., canister design and cycle parameters)
- Fabricate test article and execute test series
  - Evaluate sorbent efficacy for go/no go to next larger scale
  - Validate and refine simulation
- Repeat while increasing scale until full-scale for the process of interest is attained
- Incorporate the full-scale system into the integrated AR test configuration and evaluate via integrated testing
- Provide technology solution to spacecraft flight system developer

IBD (experiment)

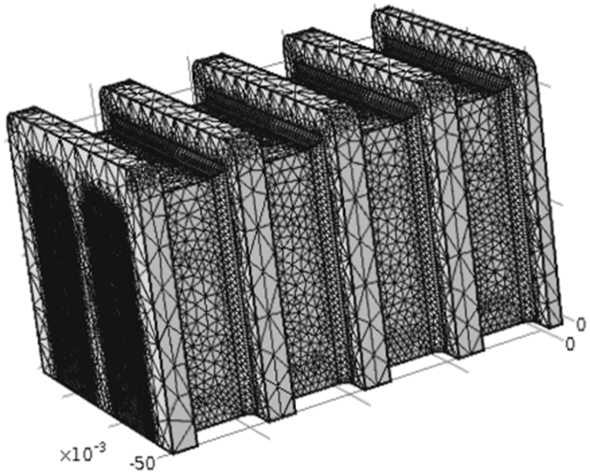
- Grace grade 40 silica gel
- Aluminum housing
- Numerous valves
- Heat exchanger plates with holes
- Meshes and spring plates between the 4 cells
- Meets performance goals
- Very nearly isothermal

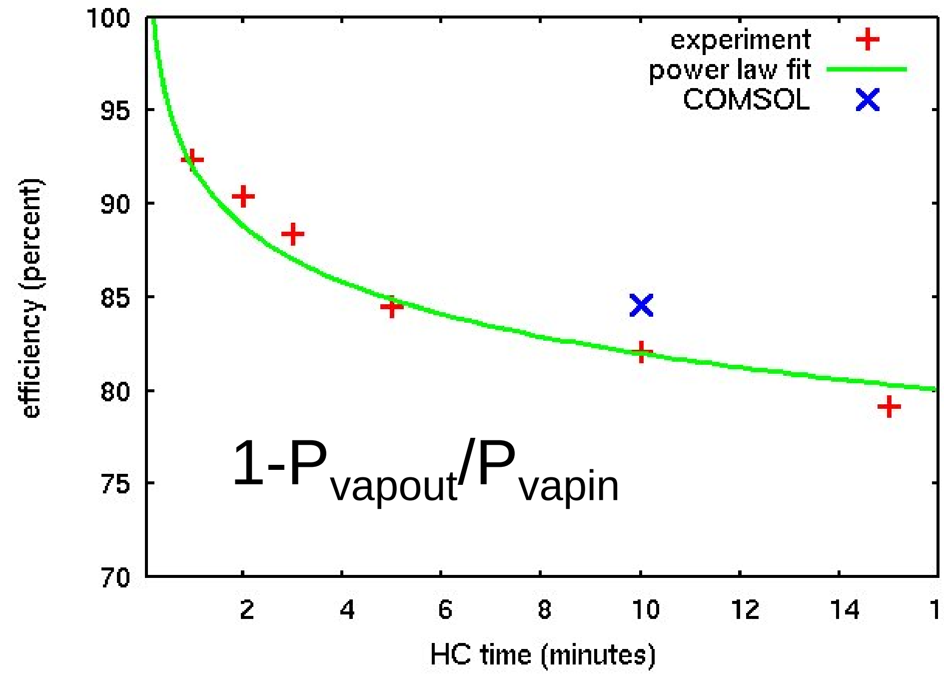




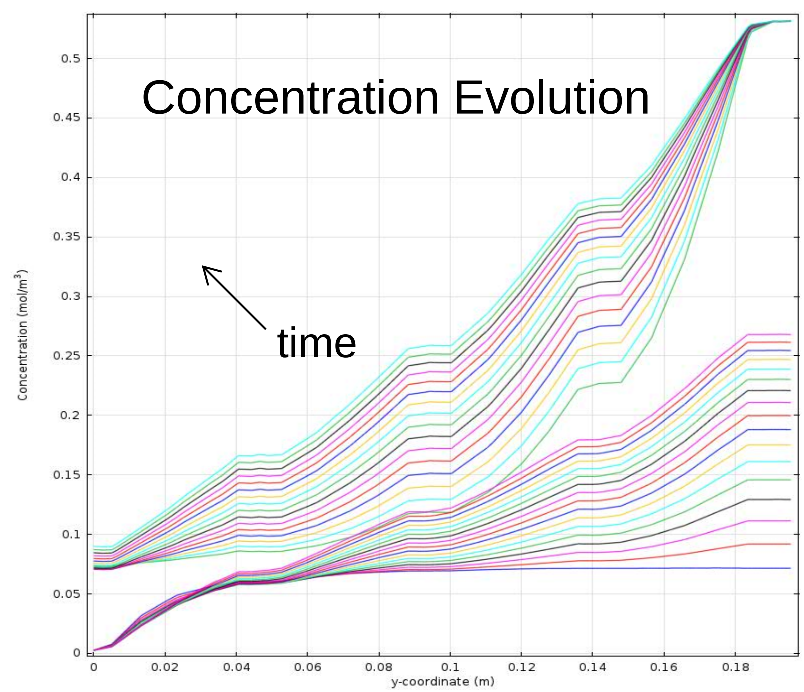
1/3 scale of system required for 4 person crew. Cooled (60ºF) air flow at 190/160 slpm with 10 ºC dew point.

IBD (model)



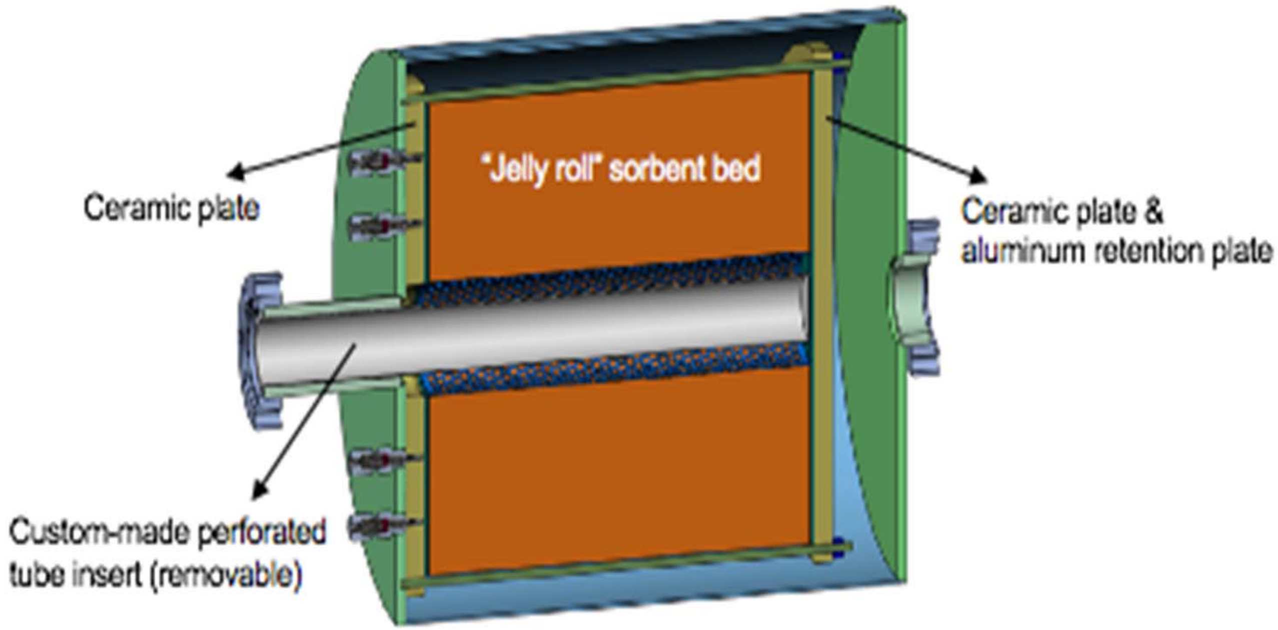


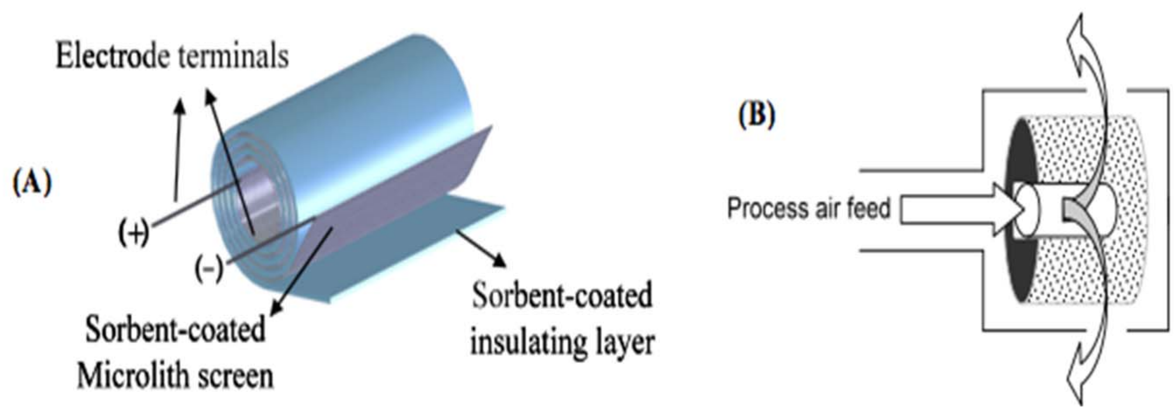
- Simplified 3D COMSOL model with HX plates as porous media
- Tracks concentration, temperature, flow path, loading
- Spatially varying porosity and permeability
- Qualitative match but not yet sufficiently quantitatively predictive



Microlith (experiment)

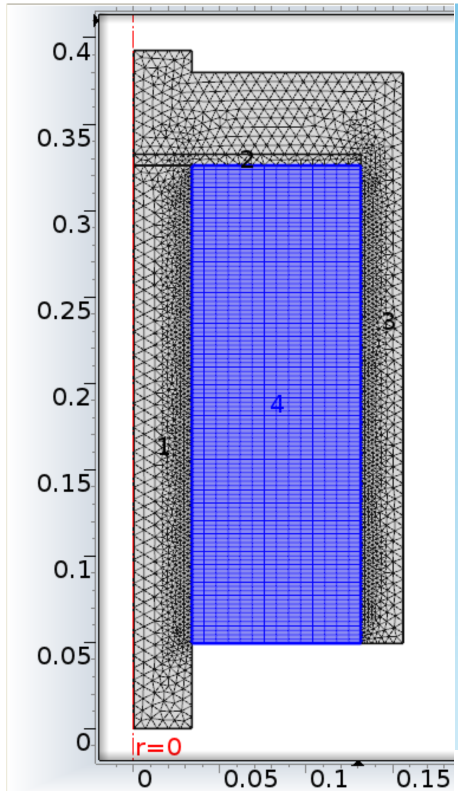
- 13X zeolite coated on Al mesh, alternating with insulating sorbent layers
- 10 sorbent-only meshes on outside of roll
- 566 slpm, 22 ^{0}C air, -10 ^{0}C dew point

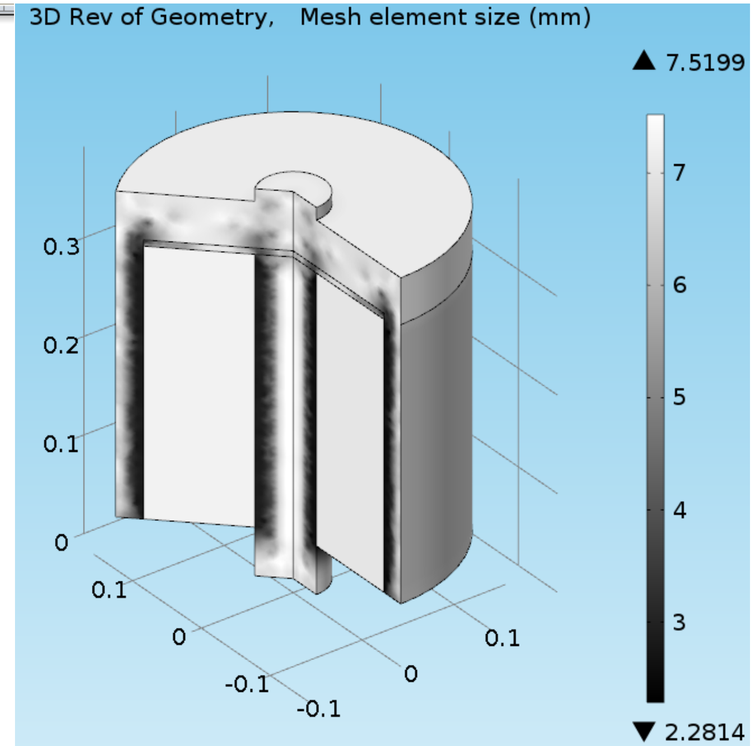


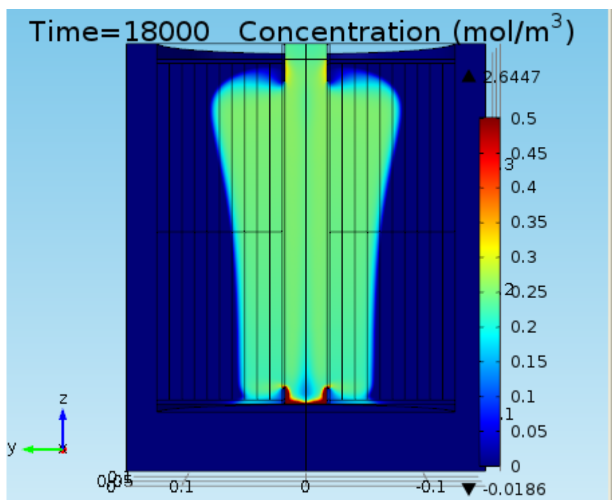


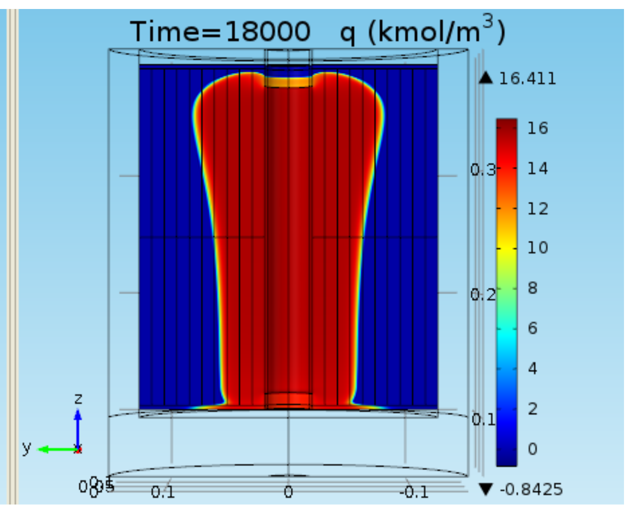
Microlith (model)

- Flow is from the top (meshes are upside down)
- Finely resolve mesh required
- Similar approach to IBD
- Constant porosity and permeability (fit to pressure drop)
- Thermal coefficients used
- Complex flow at bottom plate
- Breakthrough occurs non-uniformly
- Numerical issues (negative c and q)





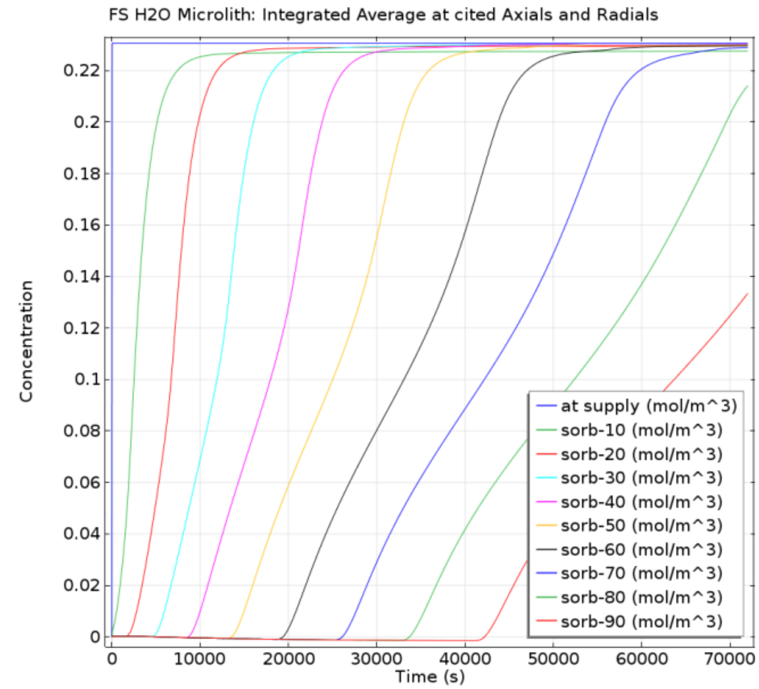


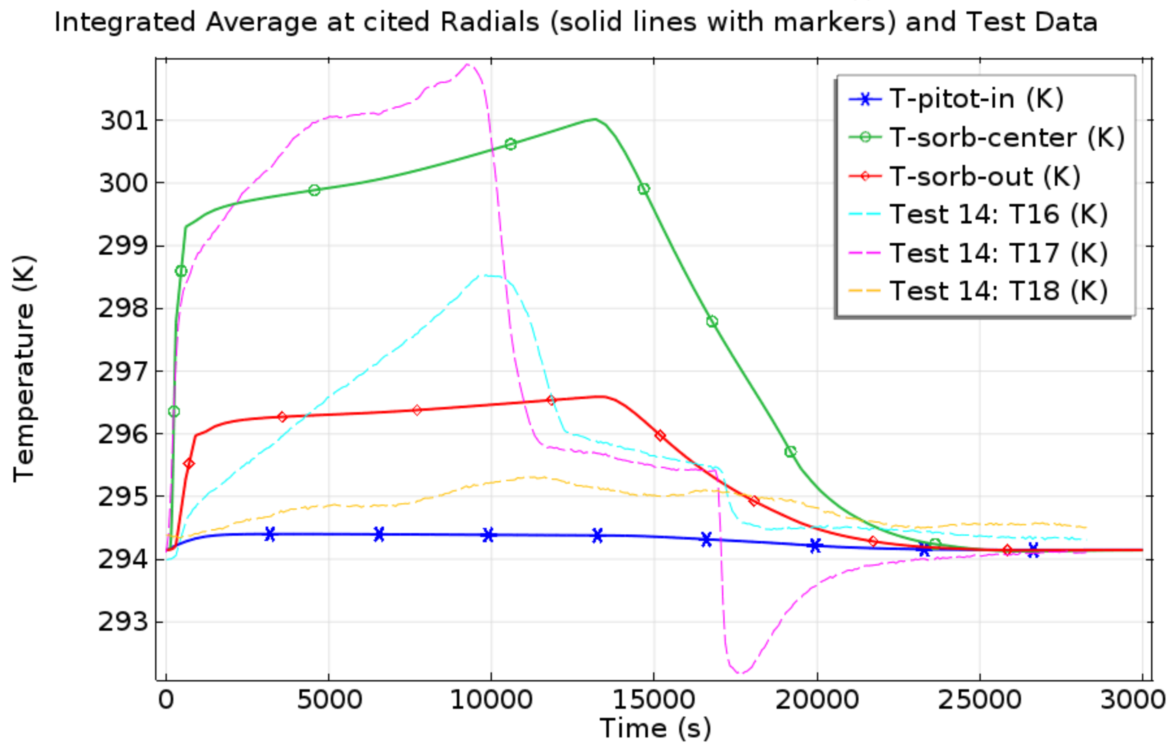


Microlith (model)

- Initial breakthrough at ~10-15k sec
- Full bulk breakthrough after ~20 hrs
- Model temporal shape incorrect (not steep enough)
- Model too late and cold
- Variable effective porosity and permeability needed?

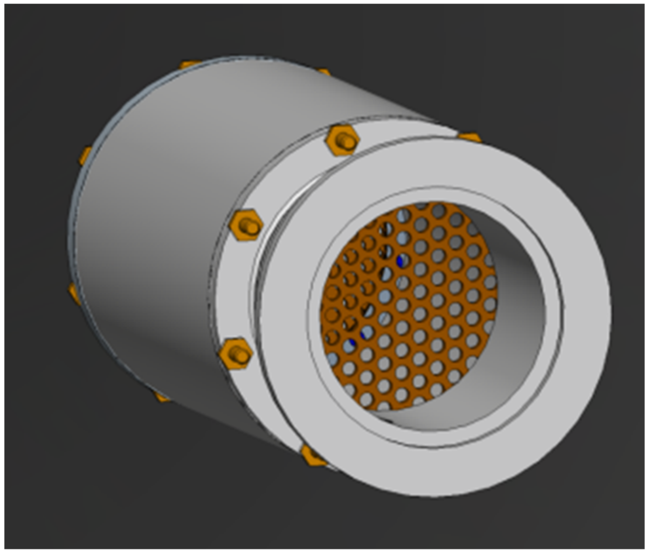
Skirt needed rather than padded shoulders





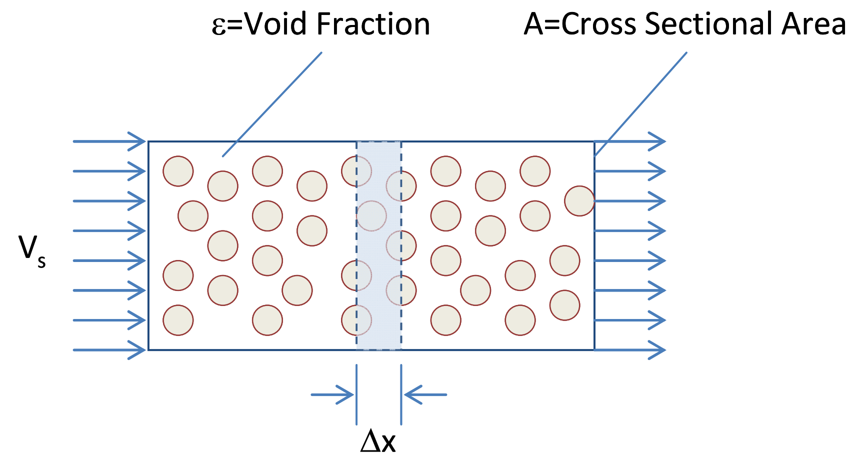
VSA POC (experiment)

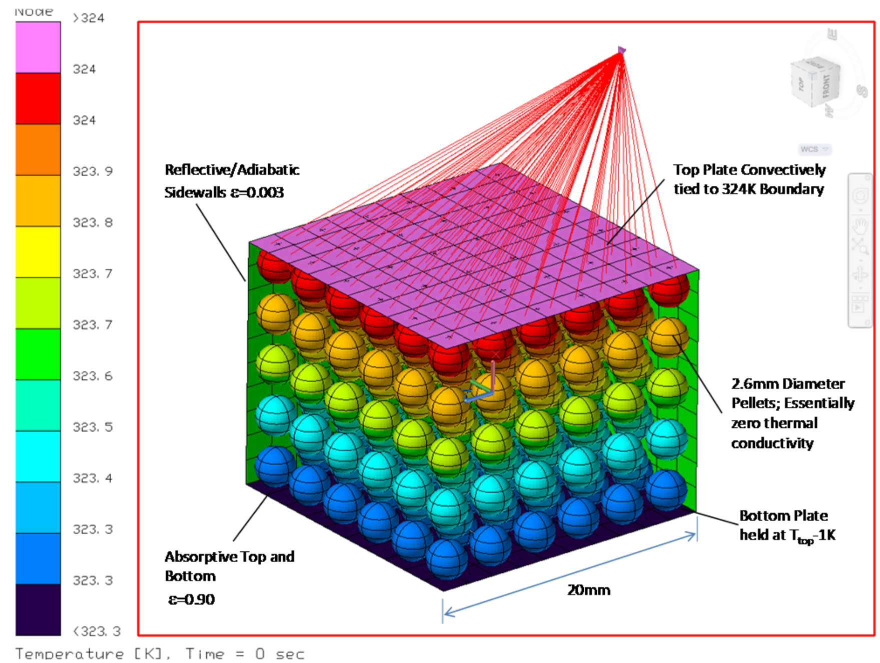
- CO2 removal and humidity control
- Zeolite 13X
- 3" diameter cylinder
- Internal sorbent bed 1" to 8" long
- Flow from left to right for adsorption
- Right end sealed and left end evacuated for desorption
- Tests to be done soon$_{\text{TM}}$



VSA POC (model)

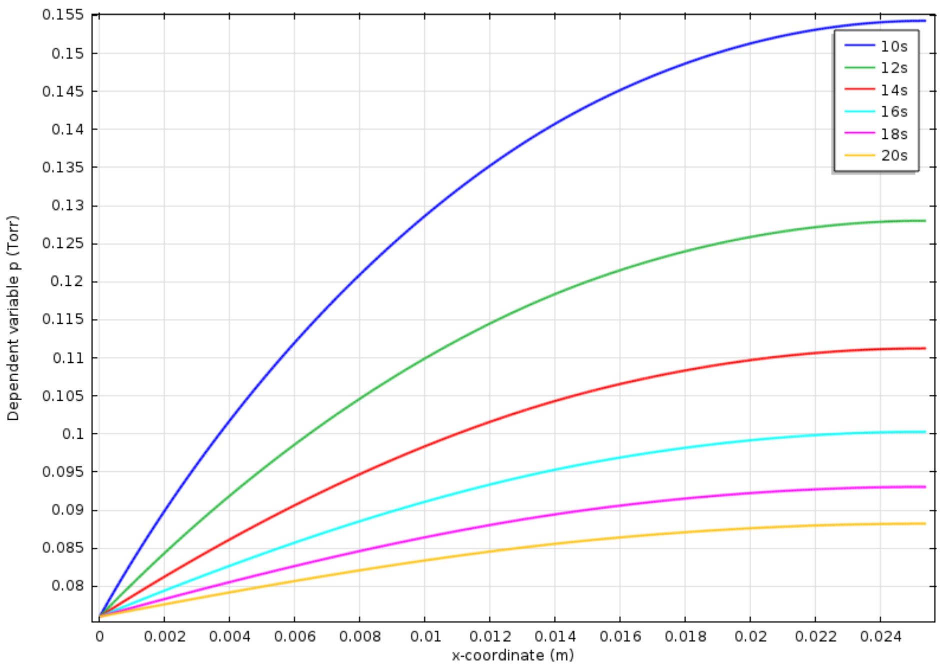
- 1D model only so far
- 1” long sorbet bed
- Constant momentum (0.1 m/s superficial velocity)
- CO_2, H_2O, O_2, and N_2 included
- Competitive sorption Toth isotherms used
- 20 ºC air with 60 ºF dew point at 1 atm with 50 sec half-cycle
- Desorption half-cycle seals right end and applies P(t) to left end and turns on an Ergun based momentum solver
- Model in Thermal Desktop showed effective radiative thermal conductivity of ~0.02 W/m/K; significant at low pressures (not included so far)

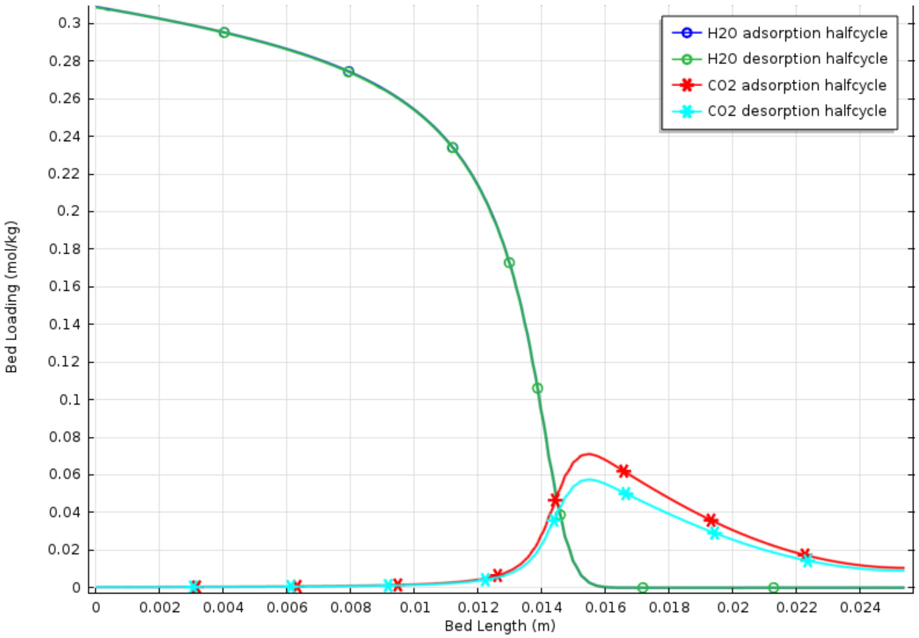




VSA POC (model)

- Boundary pressure ramped down from 1 atm over 1 sec
- Minimum pressure used of 10 Pa
- Essentially no H2O desorption occurred
  - Isotherms suggest lower pressure required to get H2O desorption
- Minimal CO2 desorption
- H2O competition with CO2 evident
- H2O eventually pushes CO2 from the bed





Conclusions

- Flat NASA budgets require innovative approaches to sorption system development
- For AES ARREM H2O and CO2 Removal, testing is being supplemented with multidimensional modeling and simulation to reduce costs and optimize designs
  - Empirical determination of mass transfer coefficients using accurate fixed bed models in 1D and 2D
  - Application of the fixed bed model in 3D to simulate cyclic sub-scale tests
  - Optimization of heat transfer for development of an Isothermal Bulk Desiccant
  - Studies of the Microlith used to troubleshoot performance problems and design subscale test
  - Developed the appropriate, simplified vacuum system equations for a VSA design
- Modeling and simulation efforts will continue to maximize the effectiveness of AES ARREM H2O and CO2 Removal system designs
- Down-select of H2O removal system: NRAD and MBAD (due to mass)