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A Process with Decoupled Absorber Kinetics and Solvent Regeneration through Membrane Dewatering and In-Column Heat Transfer

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Project Objectives

Developing transformative post-combustion CO_2 capture through:

1. Enhanced mass transfer via applying 3-D printed two-channel structured packing material to control the absorber temperature profile

2. Lower the regeneration energy via
   - Implementing a zeolite membrane dewatering unit capable of >15% dewatering of the carbon-rich solvent prior to the stripper
   - Use of rich split-feed with two-phase flow heat exchanger prior to the stripper providing a secondary point of vapor generation

Project Team & Funding

	DOE-NETL	Cost Share	
Total:	$2,986,182	$748,068	$3,734,250
Percent Share:	80%	20%	100%

Project Dates	BP1	BP2
Start:	5/1/2018	11/1/2019
End:	10/31/2019	4/30/2021

Project Manager
DOE/NETL
David Lang

UKy-CAER
Project Management
Process development and integration
Bench Scale Analysis
Zeolite Development

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Media and Process Technology Inc.

Lawrence Livermore National Laboratory

Trimeric

SMG

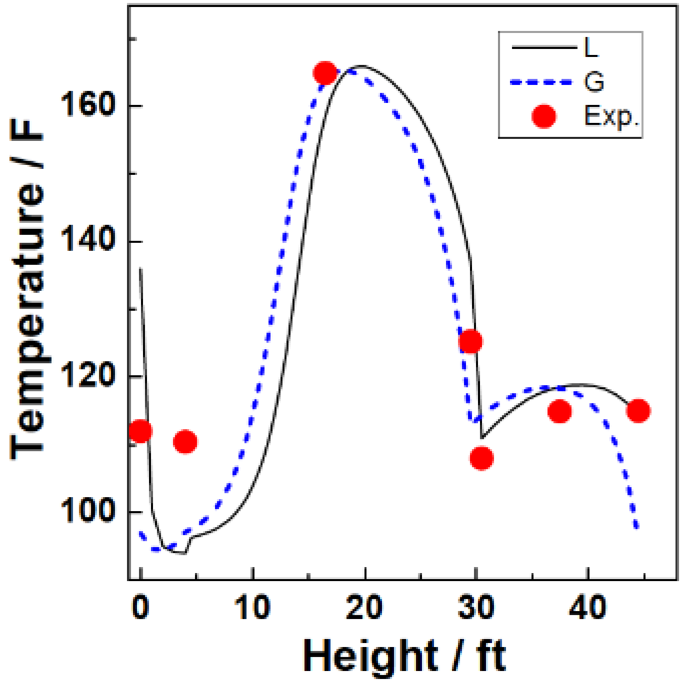
Lawrence Livermore National Laboratory (LLNL)
Packing Material

Media & Process Technology (MPT)
Membrane Module Design and Fabrication

Trimeric
Techno-Economic Analysis

Smith Management Group (SMG)
Environmental Health & Safety

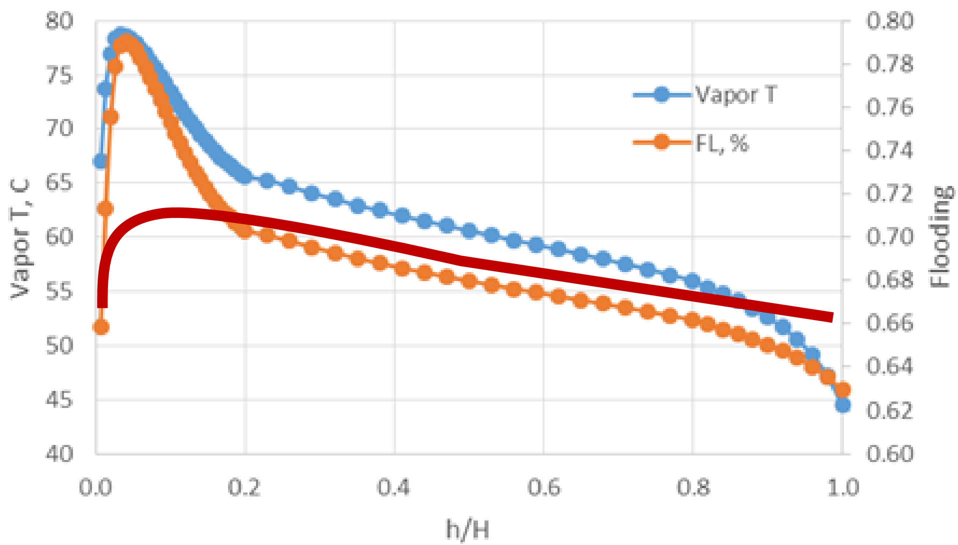
Background: Absorber Temperature Profile

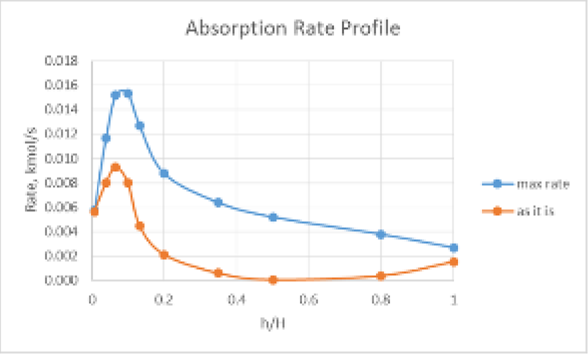


A "temperature bulge" is present near the middle of the column.

Higher temperature will impede additional absorption of CO_2.

Absorber ID and height will be reduced if the internal temperature is managed.

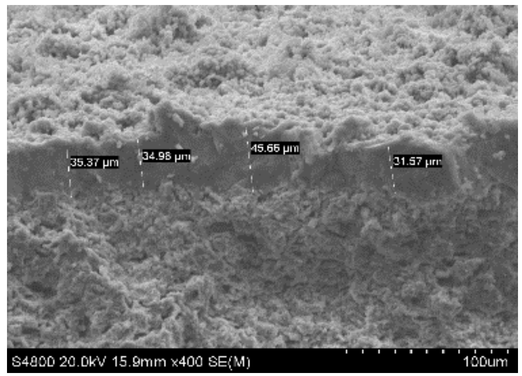


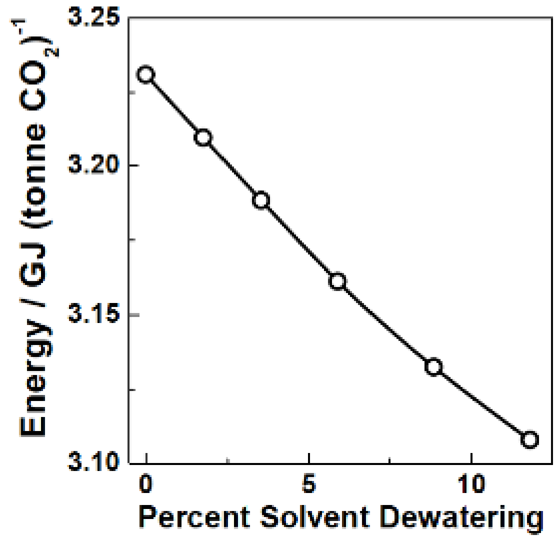


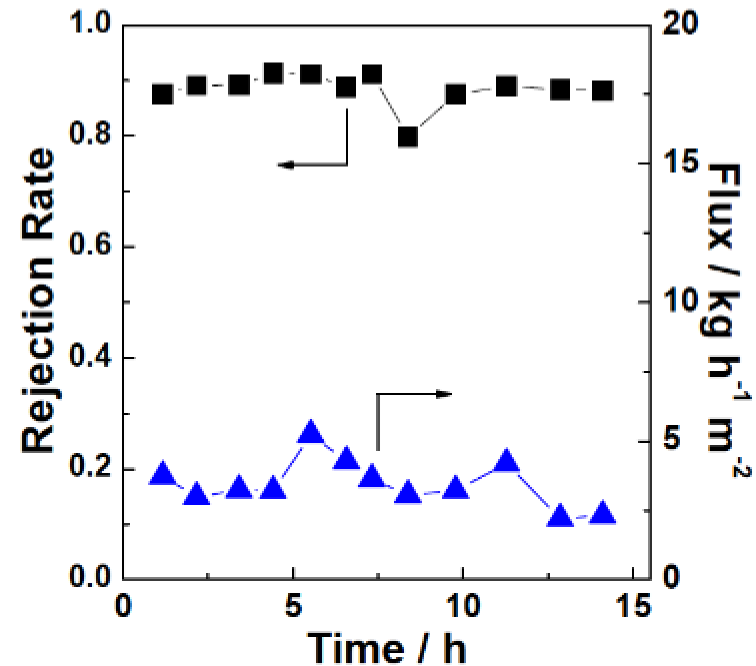
Background: Zeolite Membrane Modules

- Work previously conducted on catalytic zeolite (T) and dewatering (Y)
- Focus on membrane synthesis and modular configurations

Commercially used for water separations

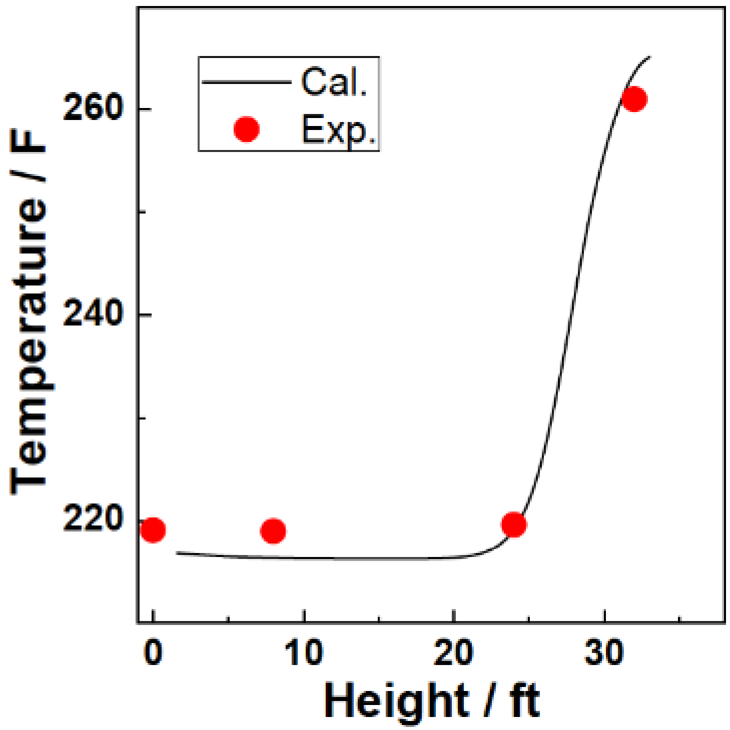


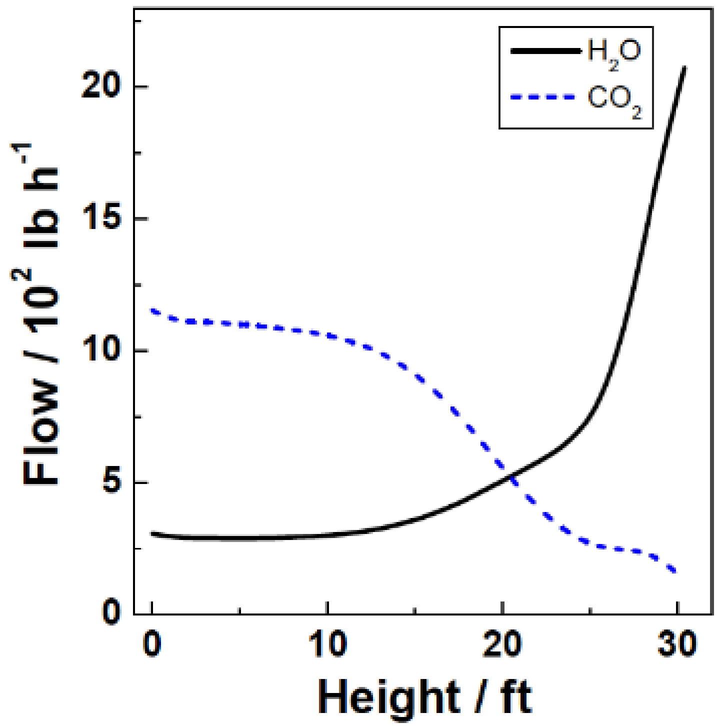




Dewatering of the process solvent can reduce the energy of regeneration

Background: Advanced Stripping & Secondary Vapor Generation Point

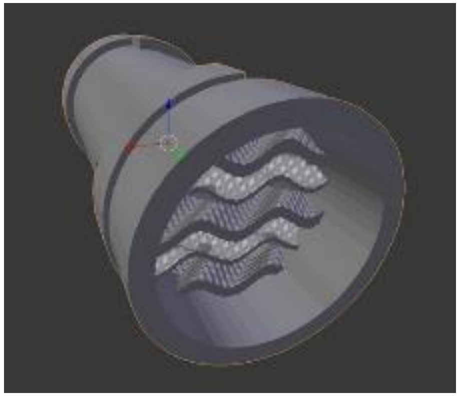




Temperature (left) and flow (right) conditions inside a stripping column. Towards the top of the column, the temperature will rise and significant energy will be expended to vaporize water (lower CO_2/H_2O ratio).

Project Approach

1. Use of 3D printing to implement heat transfer channels into the packing material, providing cooling (>150 W on the UKy-CAER small bench unit) without need for both packing and intercooling sections.



2. Achieving >100 m^2/m^3 of membranes for a dewatering module, lowering the footprint/volume of the dewatering process while demonstrating fluxes of >10 $kg/m^2/h$ to decrease membrane area/cost.

3. Use of a secondary entry point between two packing sections in the stripper with a high-end heat exchanger (using the lean amine stream)

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Project Task Schedule & Success Criteria

Task	Title	Year 1	Year 2	Year 3
1	Project Management and Planning			
2	3-D Printed Packing Material for Absorber			
3	Zeolite Dewatering Module Development and Fabrication			
4	30 L/min CO2 Capture Bench Unit Evaluation			
5	Test Plan Development			
6	Evaluation of Proposed Technique at 0.1 MWth Post Combustion CO2 Capture Facility			
7	High Packing Density and Performance Zeolite Y Membranes			
8	Composite Zeolite and Alternative Dewatering Membrane			
9	Techno-Economic Analysis			
10	Topical Report Preparation and Submission			

Decision Point	Success Criteria
Budget Period 1	1. Peak Absorber Temperature Reduced by >10 °C Confirmed 2. Zeolite Y Membranes with Fluxes >10 $kg/m^2/h$ at Reject. Rates >90% 3. Dewatering Zeolite Y Module Design Complete with >200 m^2/m^3 4. Test Plan Complete for 0.1 MWth Capture Unit
Budget Period 2	1. Stripper Heat Int. >10% Energy Savings on 0.1 MWth Capture Unit 2. Long-Term Energy Savings of >15% from 1000-hour Process Study 3. Dewatering Membrane Packing Density Increase to >400 m^2/m^3 4. Aspen Model for Entire Integrated System 5. TEA Complete for Integrated Process 6. EH&S Assessment Complete for Integrated Process 7. Updated State Point Data Table for Membrane 8. Technology Gap Analysis Complete

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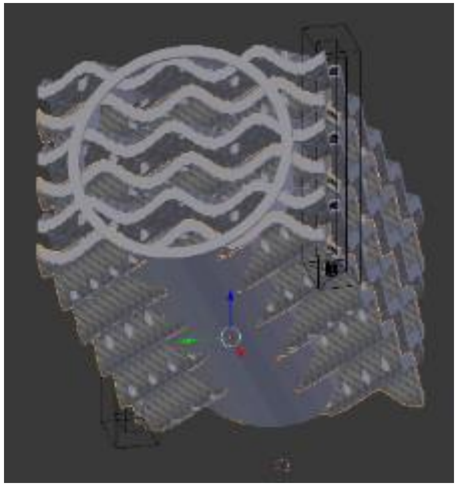
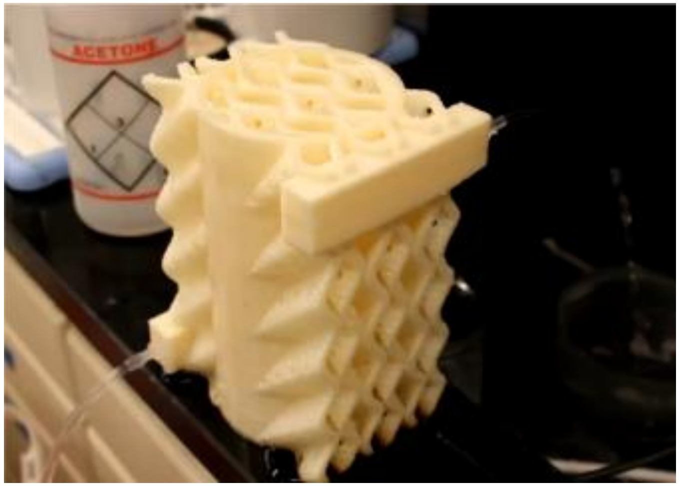
Progress and Current Status: 3D Printed Packing

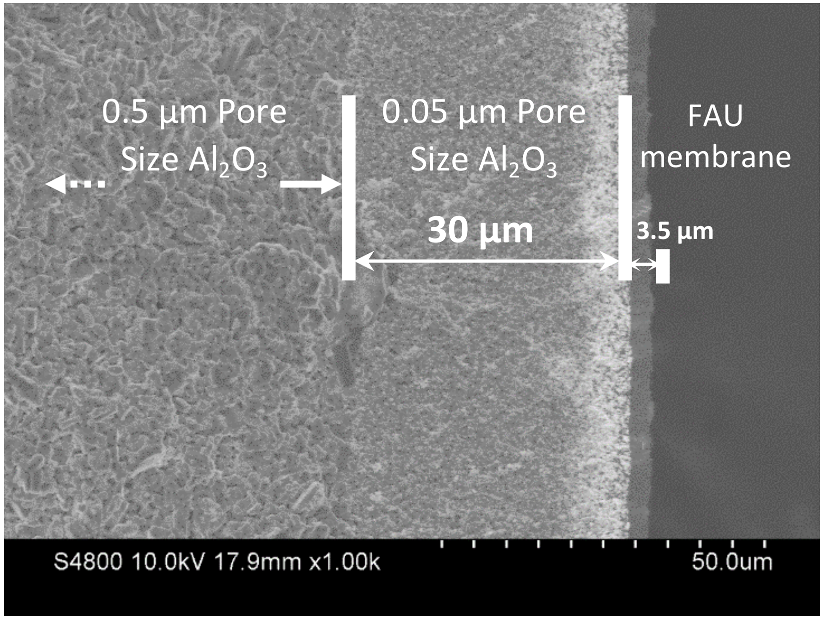


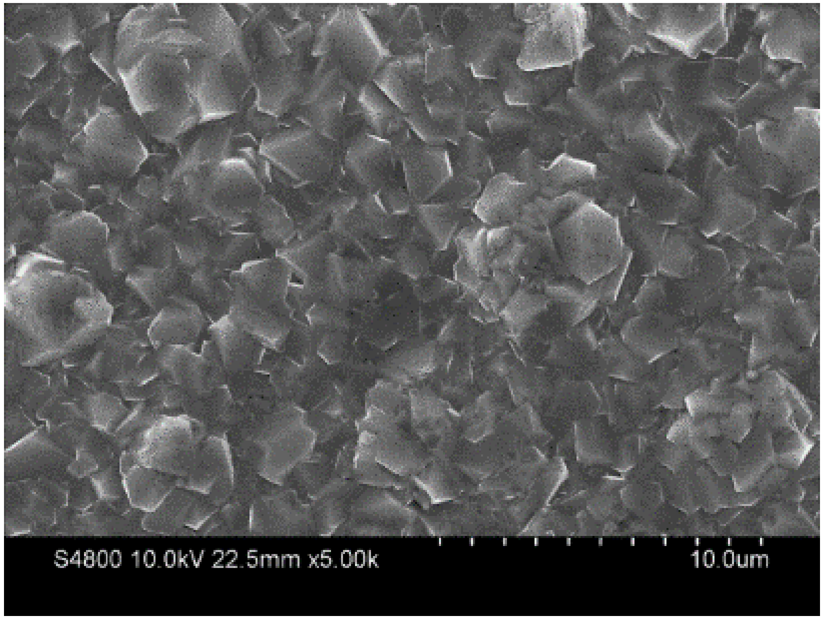


Design (left) and test print (right) for 3D printing ABS heat transfer packing material based on 250Y design from LLNL.

Heat transfer packing material from the side (left) and the top (right) using ABS material based on 250Y design with diamond “cut-outs”. Flange sealing sections added to the top and bottom for sealing in the small bench unit.

Progress and Current Status: Zeolite Membrane

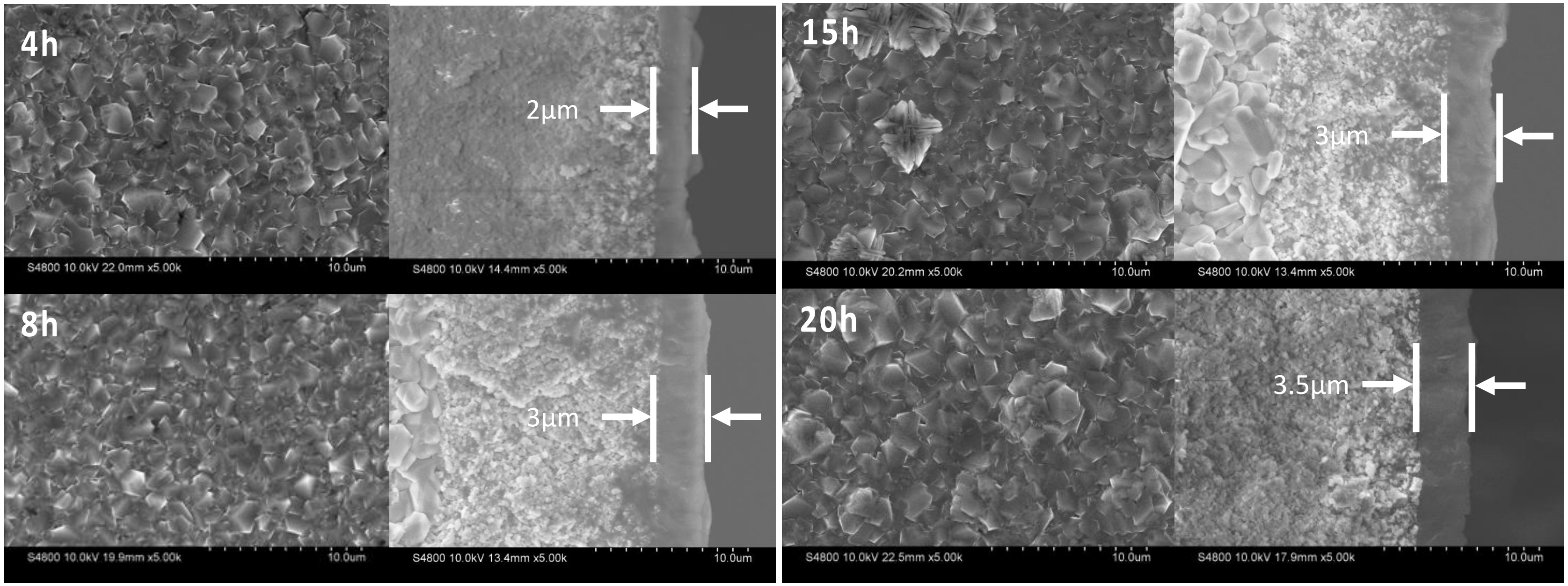


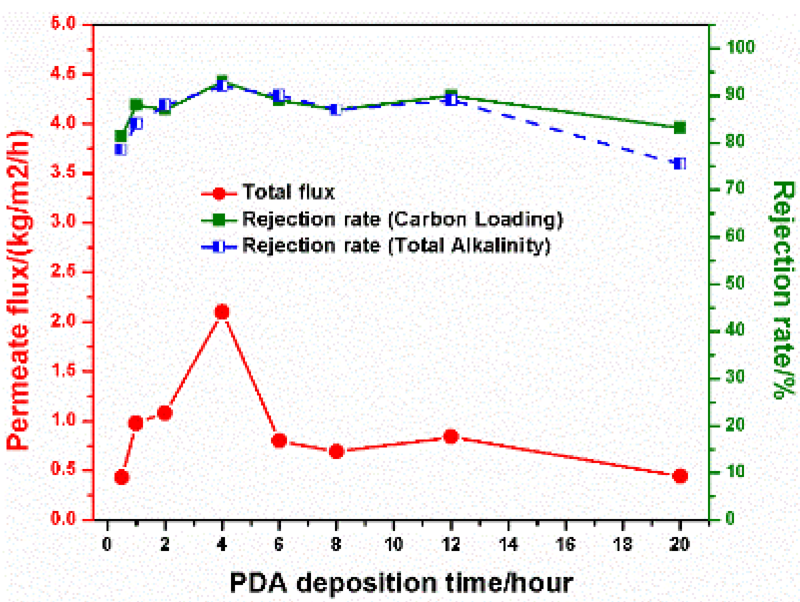


***Use of dense alumina surface layer provided by Media & Process Technology with 0.05 µm pore size**

Molecular seeding with polydopamine was to accomplish a high quality membrane with ease of deposition uniformity to deliver a more reliable complete membrane during scale up. For this seeding process, a dense alumina layer with a 0.05 µm pore size over top of a porous alumina bulk was generated from MPT to confine the molecular seed particles to the surface of the alumina.

Progress and Current Status: Zeolite Membrane





Dopamine (PDA) deposition time was evaluated for membrane performance. For each membrane, surface and cross-section SEM images of the zeolite layer on top of dense alumina support from MPT using dopamine deposition times of 4, 8, 15, and 20 hours. Zeolite membranes were all grown on an alumina support with a pore size of 0.05 µm from MPT using 85 °C and 11 h during hydrothermal growth.

Progress and Current Status: Zeolite Membrane

Membrane Support Materials:

1. Conventional porous alumina tubes
2. Use of mixed porosity alumina support: Dense layer on the surface and more porous underlying support.
3. More hydrophilic mullite for higher water transport

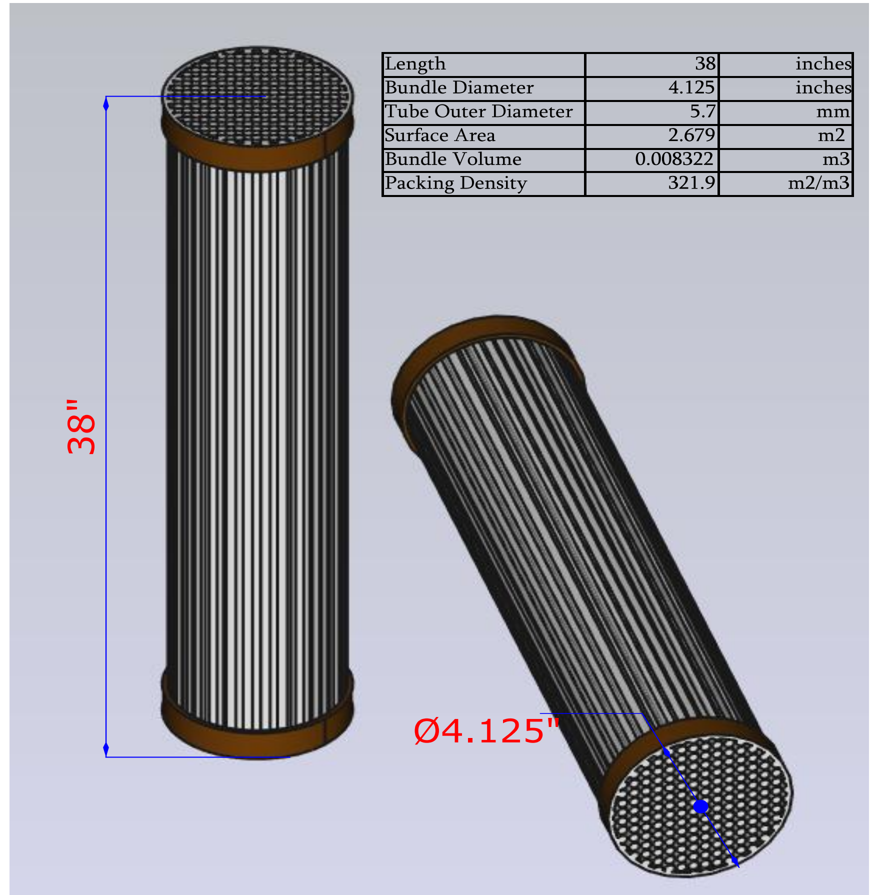
Under Evaluation:

1. Media & Process Alumina: 0.05 µm pore size dense layer, 0.5 µm pore size bulk support
2. NanjingTech AC100: 0.1 µm pore size dense layer, 0.5 µm pore size bulk support

Support/Pore Size/Seed Process	Flux / kg m^{-2} h^{-1}	Rejection Rate (C Loading) / %
MPT/0.05 µm/4 h Dopamine	8.36	>69
AC100/0.1 µm/4 h Dopamine	10.12	>88

*** Use of correct porous support to achieve higher fluxes**

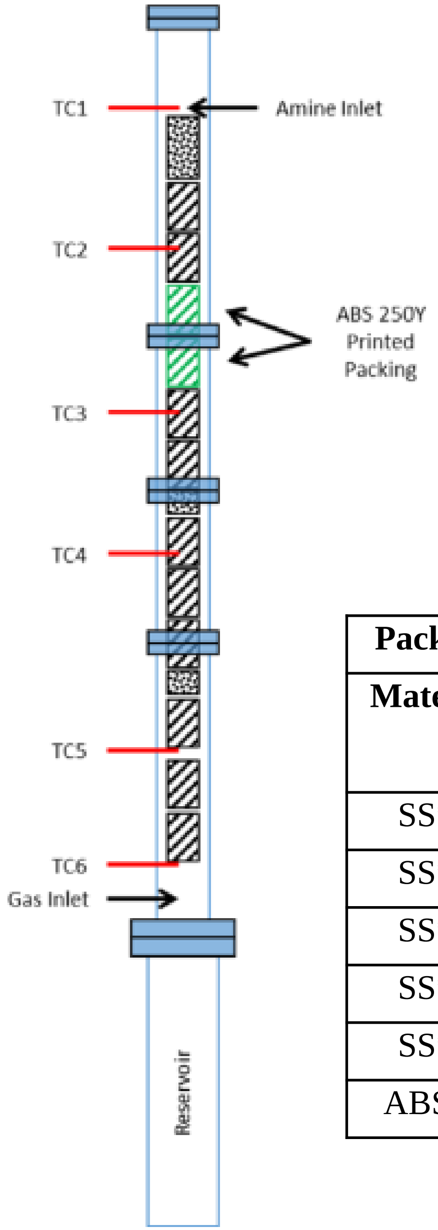
Progress and Current Status: Zeolite Membrane

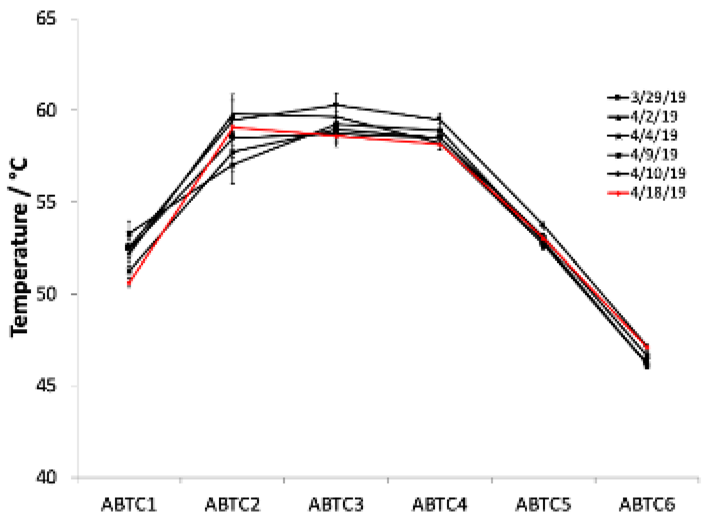


Length	38	inches
Bundle Diameter	4.125	inches
Tube Outer Diameter	5.7	mm
Surface Area	2.679	m2
Bundle Volume	0.008322	m3
Packing Density	321.9	m2/m3

Scale-up (left) and design of membrane module (above) for use in bench units at UKy-CAER are taking place at MPT. Packing density can reach ~322 m^2/m^3.

Progress and Current Status: Small Bench Unit

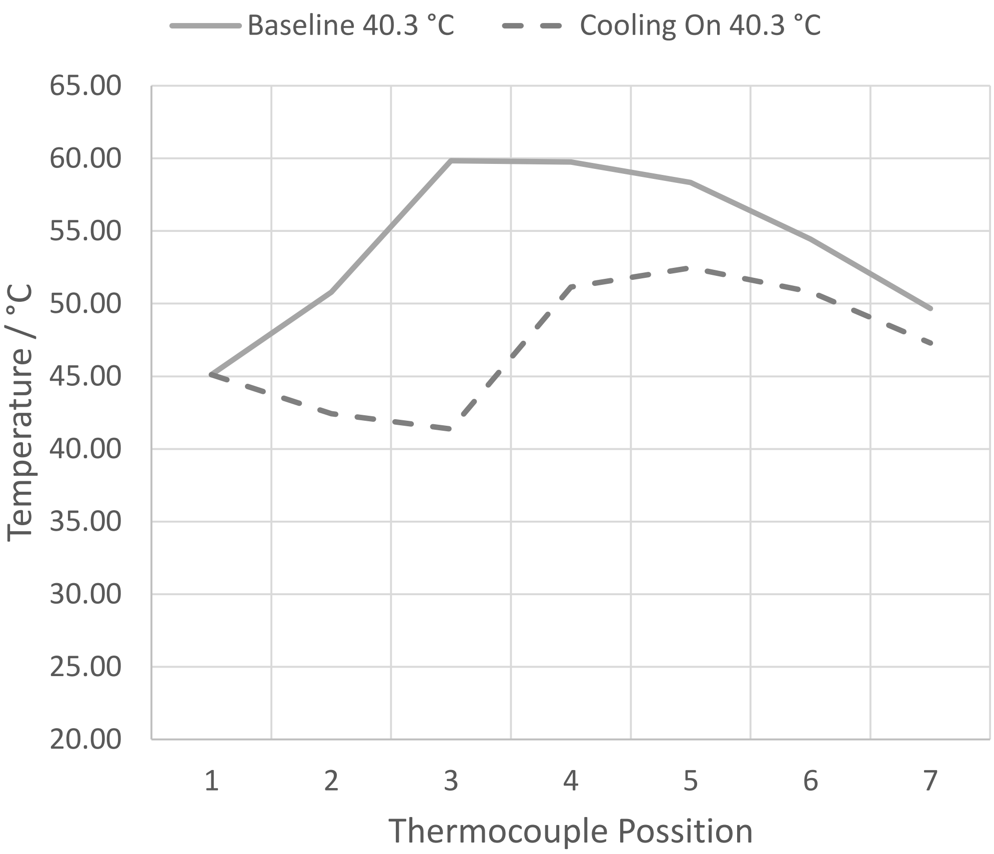




Temperature profiles with (red) and without (black) ABS 250Y packing material.

Packing Material	Packing Orientation	Amine Flow Control	Flow Rate		L/G	AB.TC.0 (°C)	Gas Capture Efficiency
			Amine (mL/min)	Gas (L/min)			
SS**	90°	Vol.	453.1	128.65	2.83	45.2	55%
SS**	90°	Vol.	451.5	128.67	2.82	45.5	55%
SS**	90°	Vol.	452.9	128.07	2.84	46.1	55%
SS**	90°	Vol.	452.3	130.47	2.78	44.5	55%
SS**	90°	Vol.	449.2	130.31	2.77	45.4	56%
ABS**	90°	Vol.	448.8	127.71	2.82	45.1	53%

Progress and Current Status: Small Bench Unit



Heat transfer packing material (HTPM) printed using FDM was installed in the absorber on the small bench unit for temperature profile baselines. A >10 °C drop is seen between TC2 and TC3.

Future Testing

Validated concepts expand to the pilot scale for further development

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