FWP-FEAA 384

Intensified, Flexible, and Modular Carbon Capture Demonstration with Additively Manufactured Multi-Functional Devices

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National Energy Technology Laboratory
2023 Carbon Management Project Review Meeting

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Project Overview

– **Funding provided by DOE-FECM:** $1.878M

– **Overall Project Performance Dates:**
January 1, 2021 – December 31, 2023

– **Previous Projects:**
Focused on design, manufacturing, and validation of intensified devices for enhanced carbon capture using MEA and low-aqueous solvents

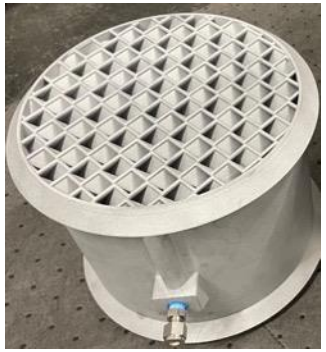
- Intensified device enhances mass transfer, just like commercial packing, and allows a third fluid (coolant) to remove the heat of reaction between CO_2 and amines
- Jang et al., "Process Intensification of CO_2 Capture by Low-Aqueous Solvent," Chem. Eng. J., **426**, 131240, (2021)

– **Motivation for the current Project: Scalability of the intensified device**

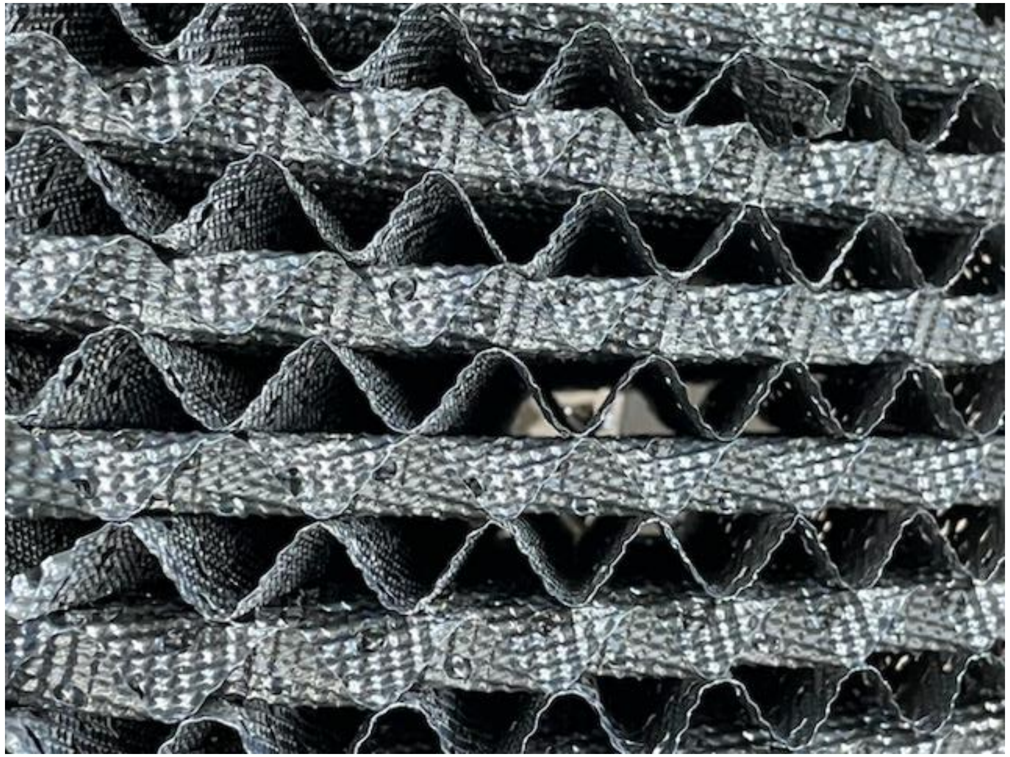
Technology Background: How the Intensified Device Works

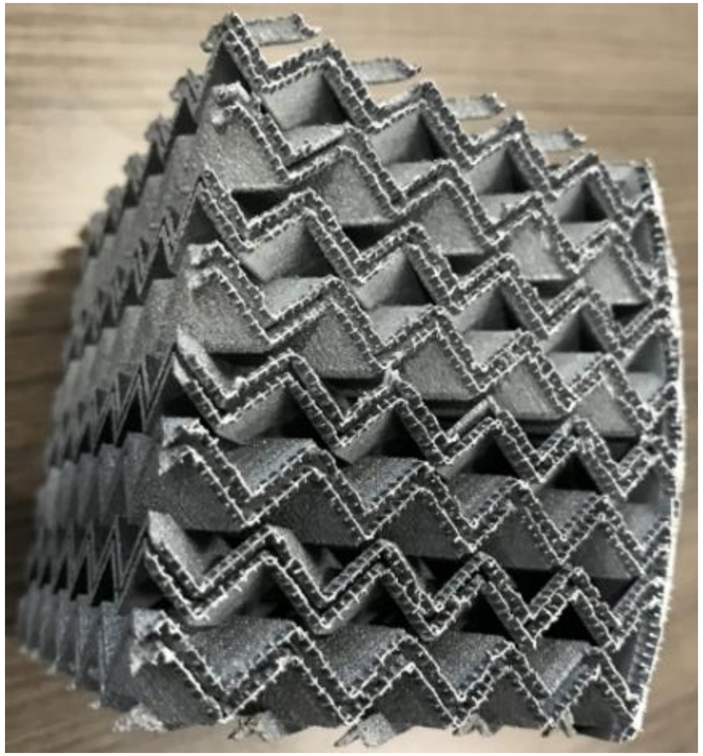
$$2\mathrm{MEA} + \mathrm{CO_2} \rightleftarrows \mathrm{MEAH^+} + \mathrm{MEACOO^-}$$ (+ 79-100 KJ/mol) (Exothermic)

Column A



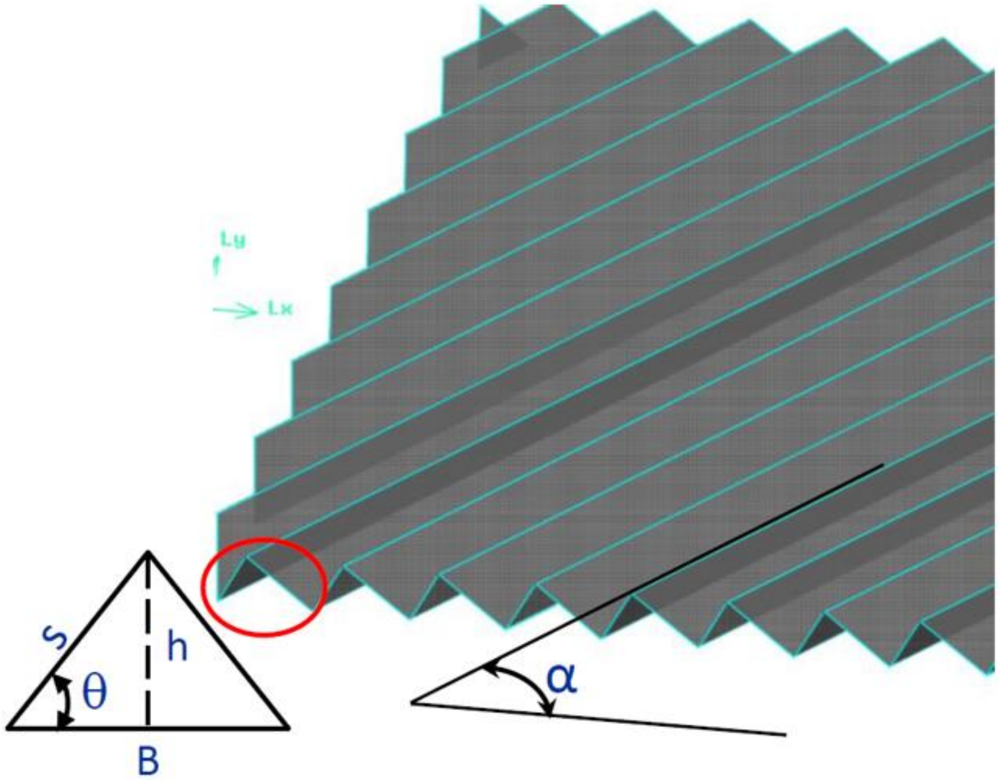
Intensified Devise

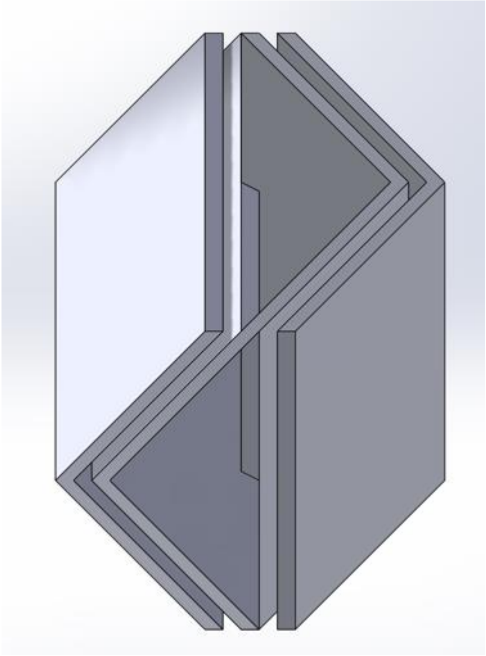


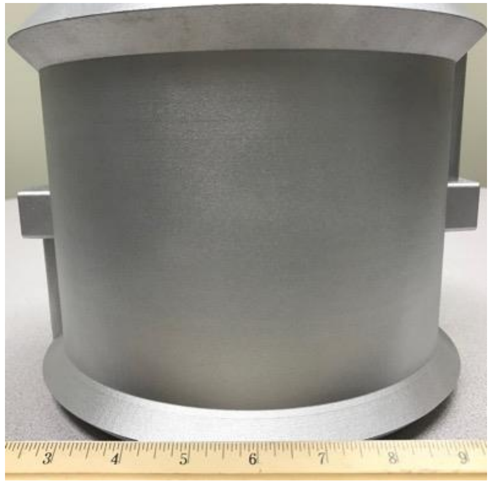


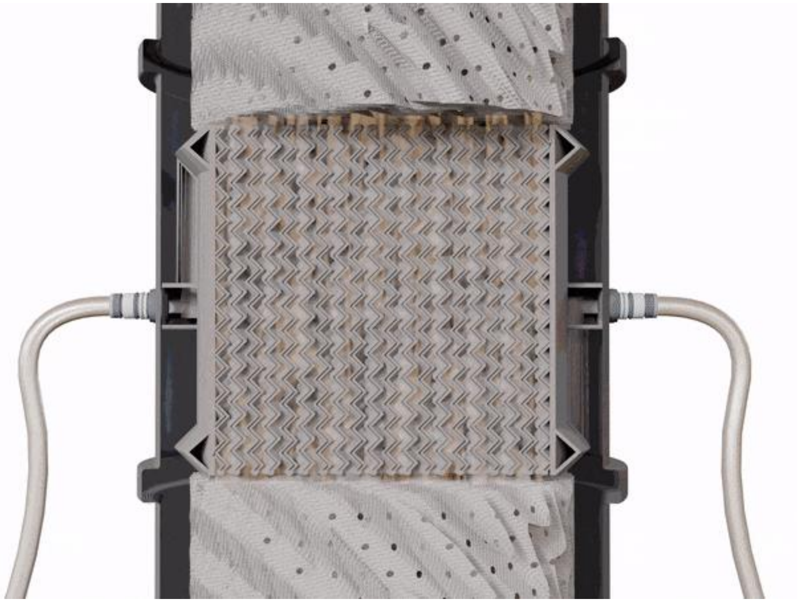
- Miramontes et al., Additively Manufactured Packed Bed Device for Process Intensification of CO_2 Absorption and Other Chemical Processes, Chem. Eng. J., **388**, 124092, (2020)

How The Device Works









- Miramontes et al. Process Intensification of CO_2 Absorption Using a 3D Printed Intensified Packing Device, AIChE J. **e16285,** (2020)

- Depending on operating parameters, 5-25% CO_2 capture enhancement was observed

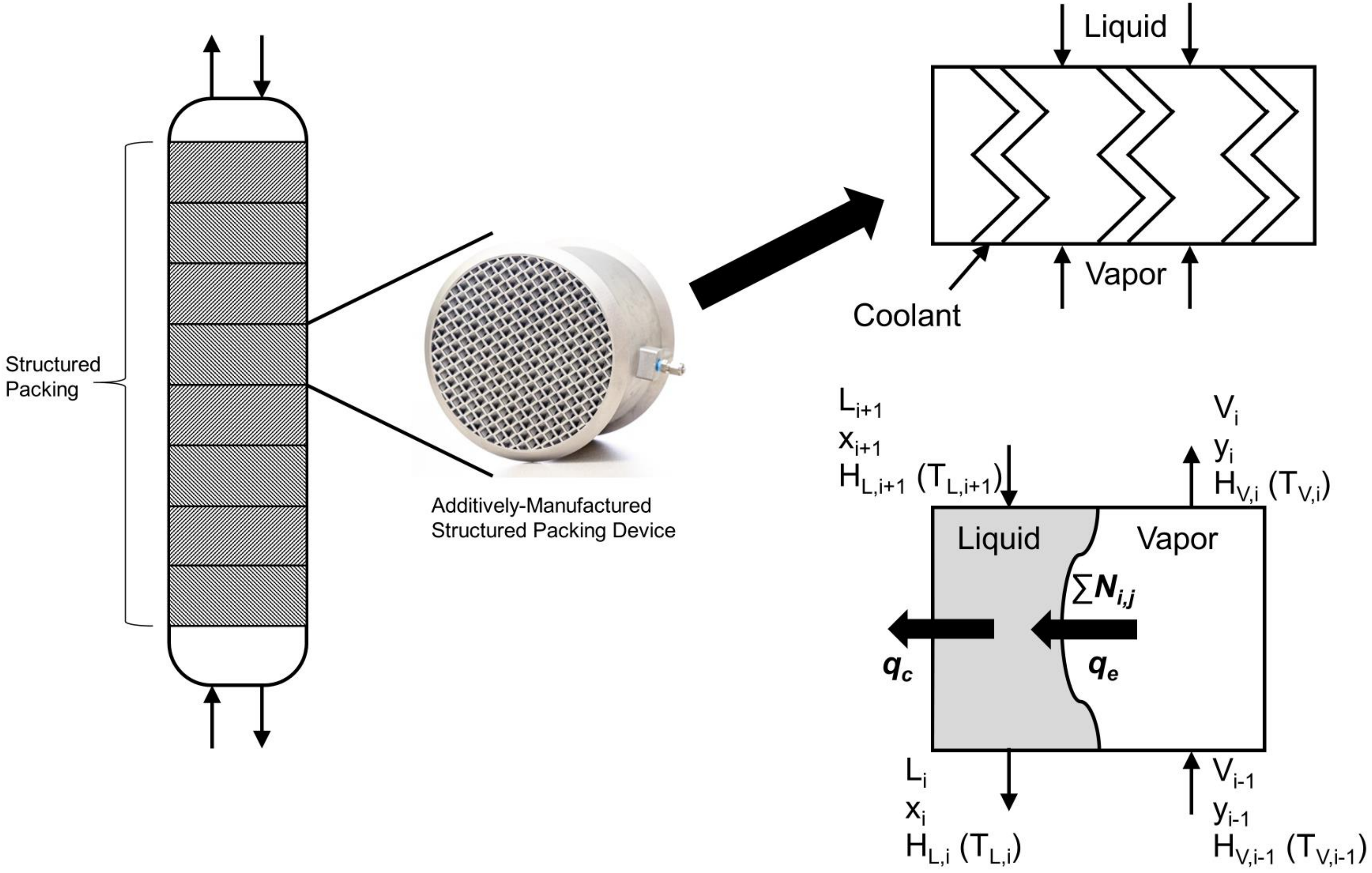
- **Safety incident in the laboratory, using Column A: Worker exposure to CO_2 solvent**
- **A Lessons Learned was published for other laboratories**

Overall Project Objectives for FEAA 384

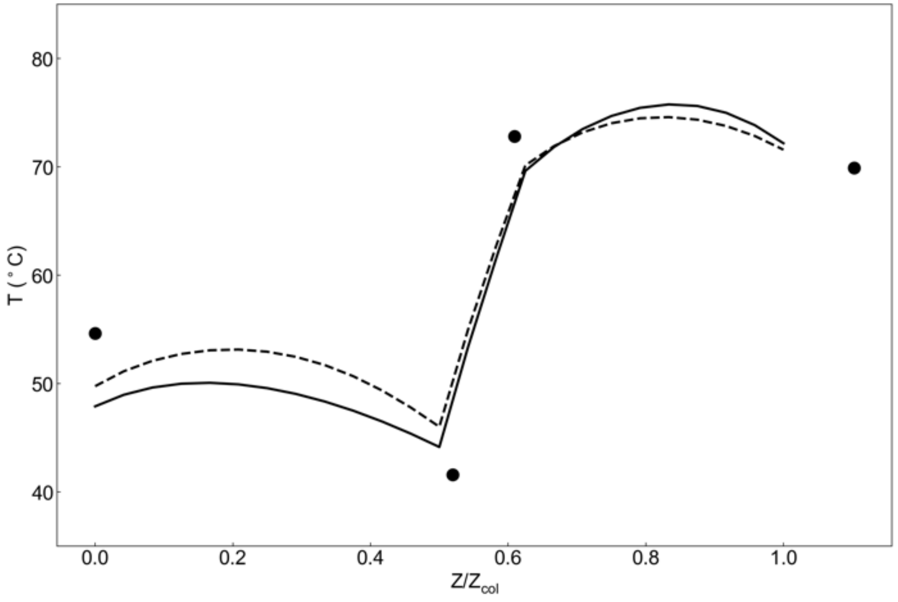
- Design and construct a larger-scale column (Column B) than the one previously tested (Column A)
- Scale up CO_2 capture from 0.1 t/day to 1 t/day
- Demonstrate Column B construction with modular packing elements and intensified devices
- Demonstrate 15% enhancement in CO_2 capture for aqueous and low-aqueous amine-based solvents at realistic operating conditions
- Demonstrate effective capture for different CO_2 gas compositions and during process transients, with capacity ramping up and down anticipating the intermittency of renewable energy

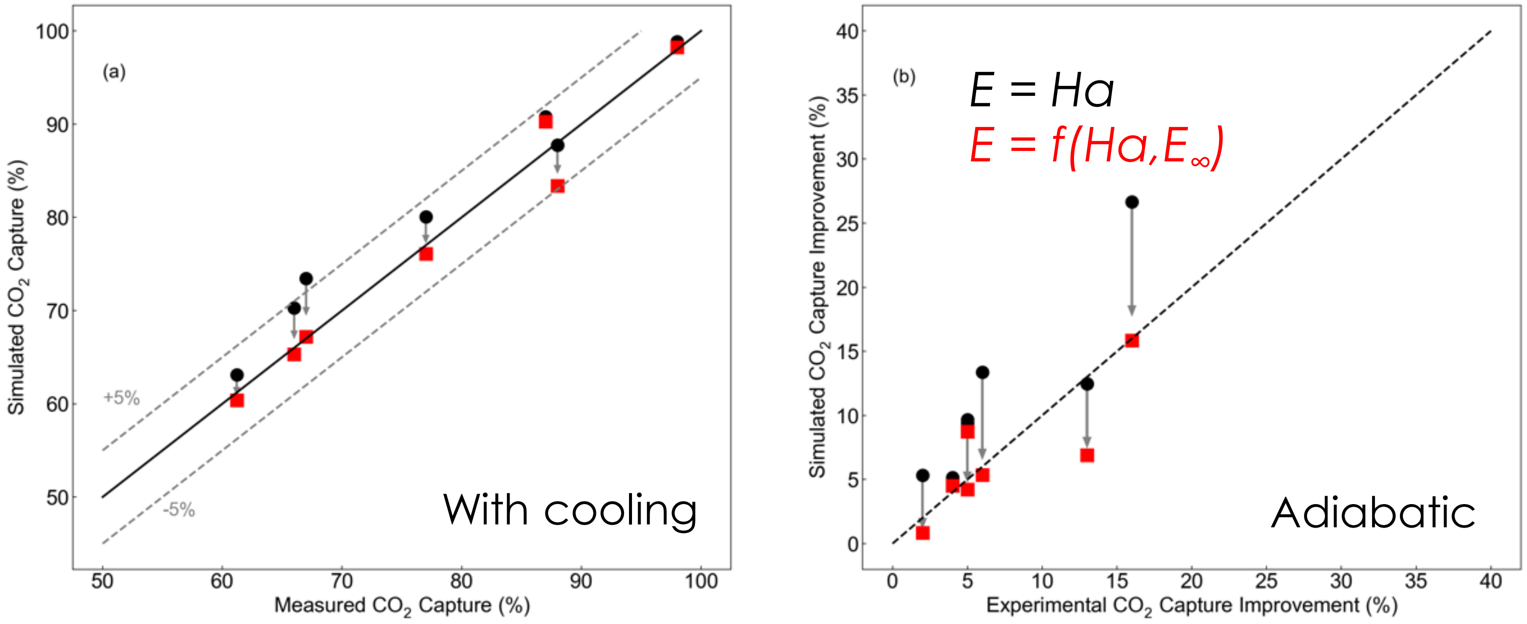
Task 2.0 – Design Evaluation and Construction of Column B

Modeling Framework:



Modeling MEA w/Intrastage Cooling

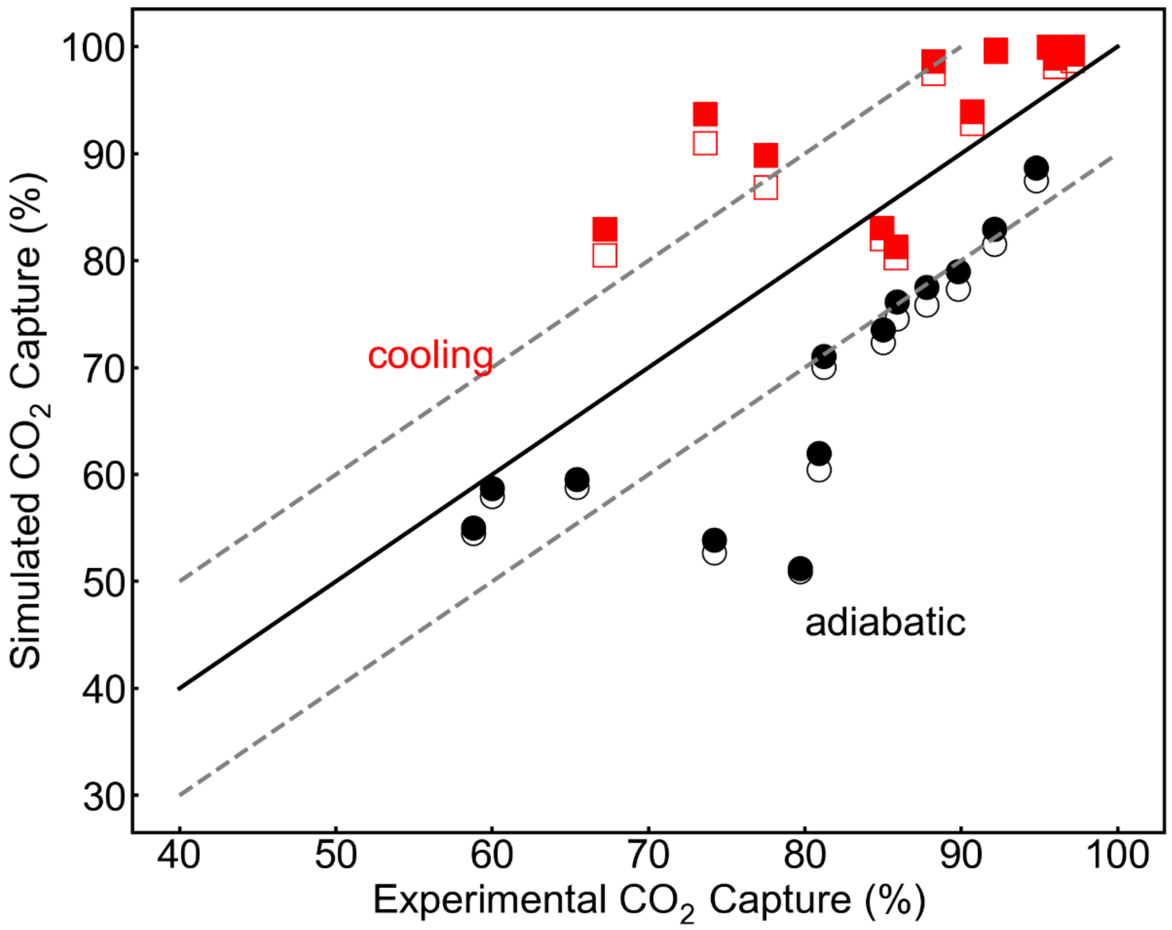




- Simulation of intrastage cooling with device showed good agreement with experimental data from Miramontes *et al*. (2020)
  - CO_2 capture difference: all <= 5%
- CO_2 capture improvement and temperature profile agreement suggest modeling framework for heat transfer is accurate in predicting device performance

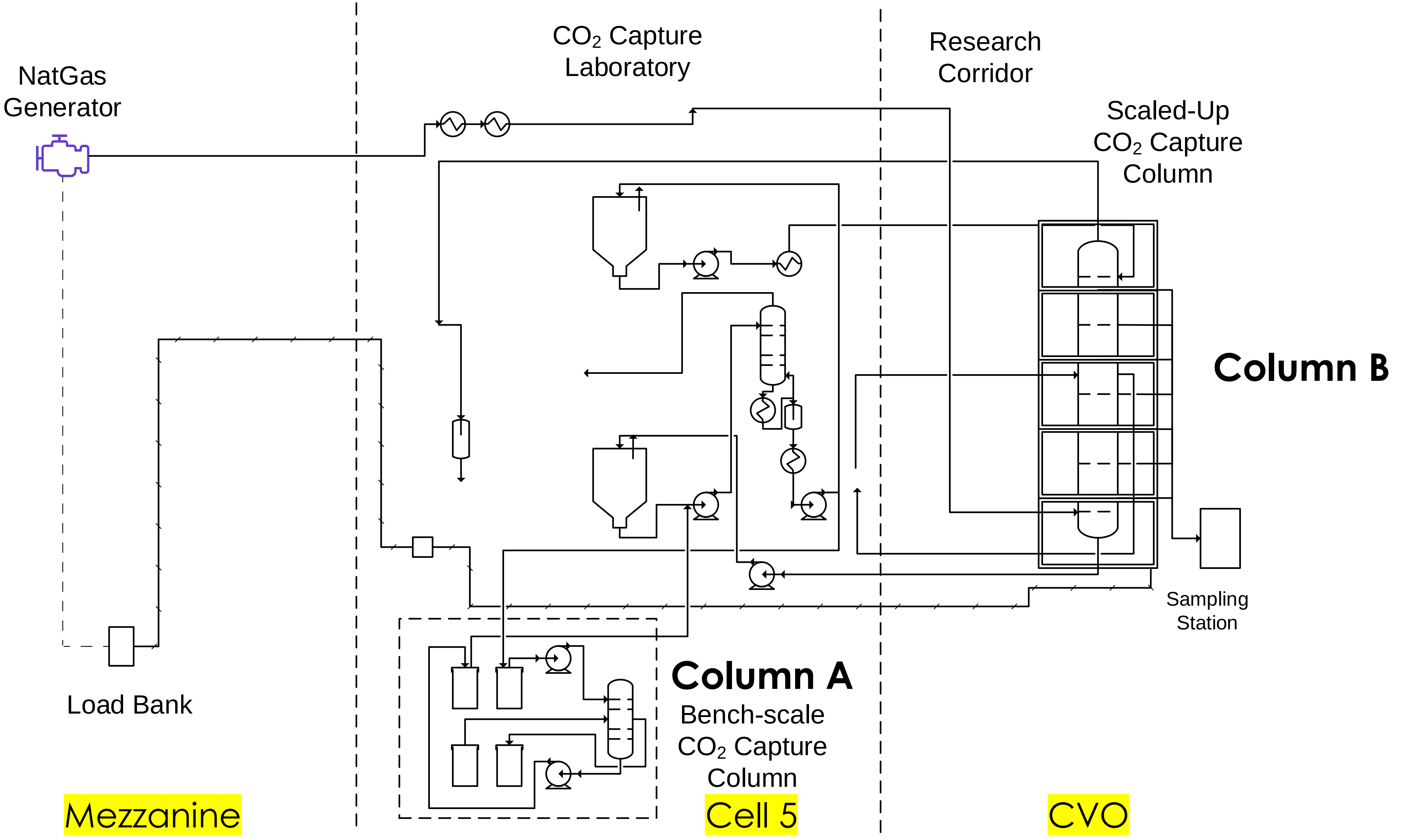
Thompson and Tsouris, "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing", *Ind. Eng. Chem. Res.*, **2021**, *60(41)*, 14845-14855.

Modeling RTI's Low Aqueous Solvent w/Intrastage Cooling



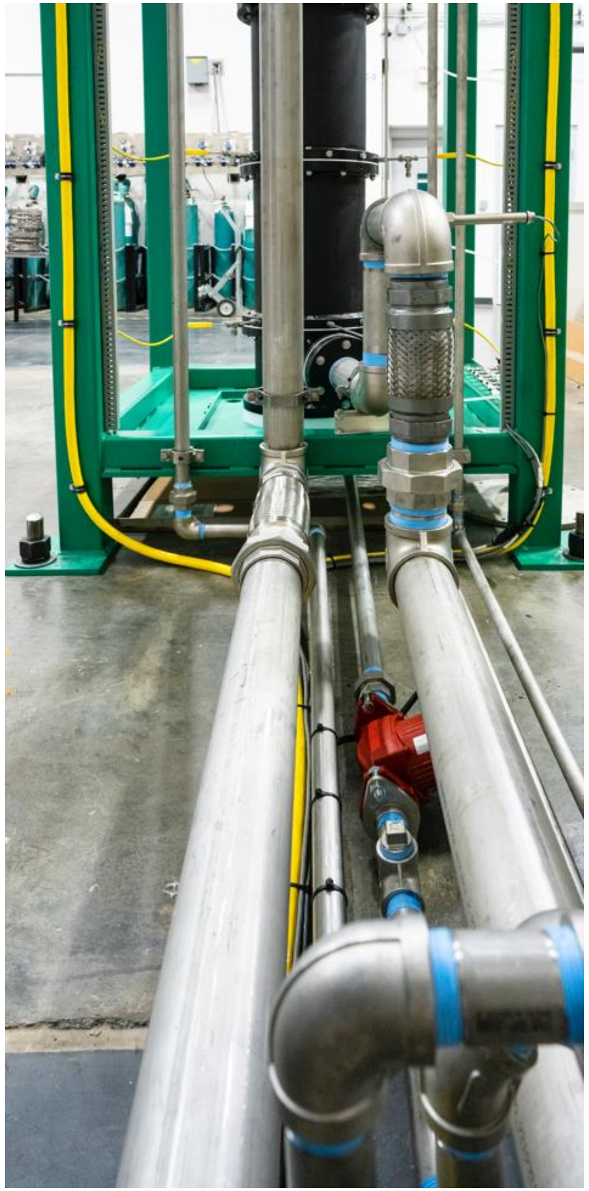
Simulated vs experimental CO_2 capture rate of LAS under adiabatic (black) and cooling (red) conditions. Closed symbols are predictions from *Model 1*, and open symbols are from *Model 2*. Solid black line is parity line, and dashed lines are +/- 10% capture rate.

Process Diagram for Column Design

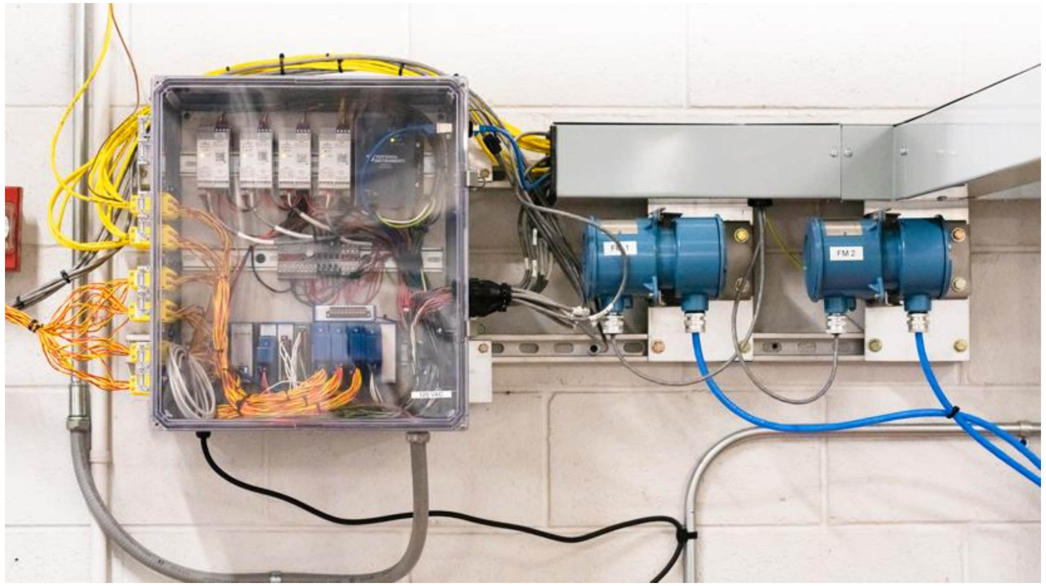


Process flow and equipment essential to proper design around absorption column

Column B Construction: Equipment in CVO Area



Column B Construction: Equipment in Cell 5



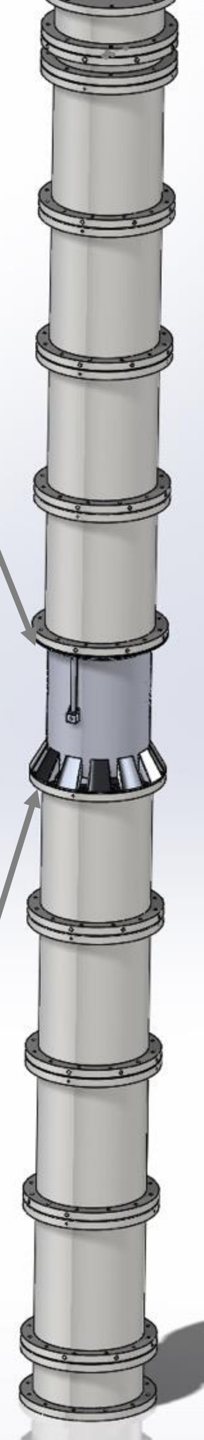
Task 3.0 – Advanced Manufacturing and Core Metrics Testing of Intensified Device for Column B

Scale-up from 8” to 12” Diameter

- New unit cell geometry: Column A

- Added flanges for device integration with the column
- Added supports for printability

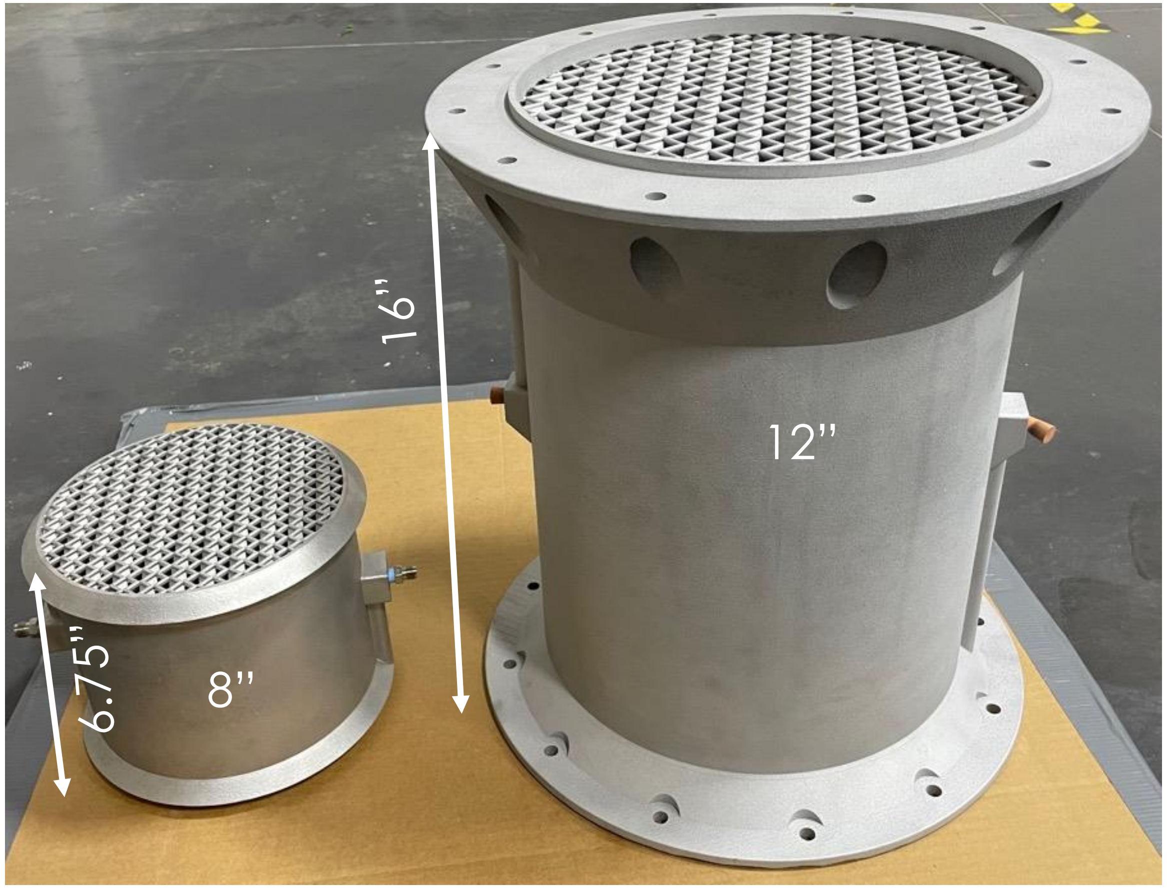
Design of 12-inch device



For Column B

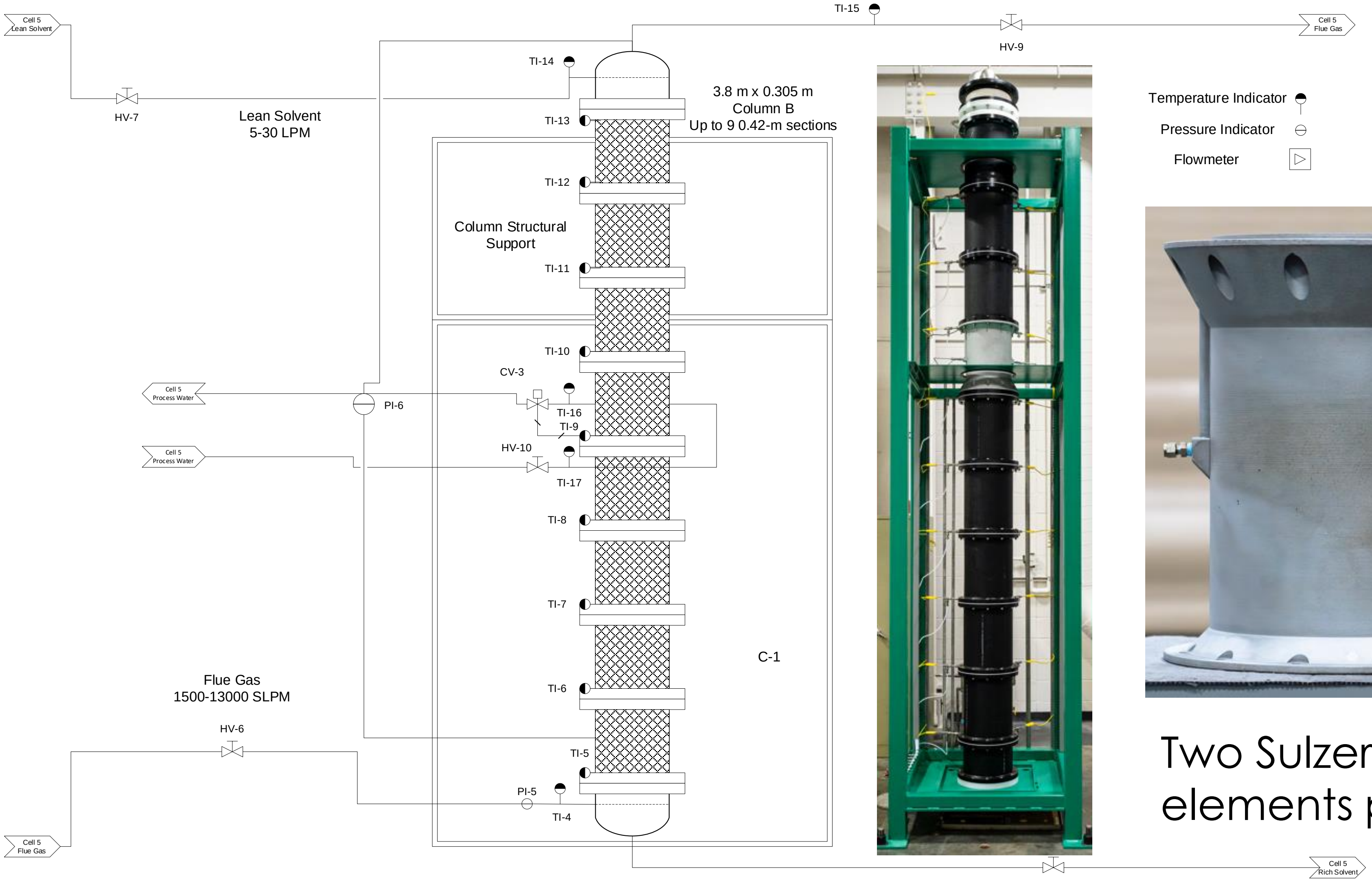
Scaled-Up Intensified Devices

12-inch diam., 16-inch height



8- and 12-inch devices
(volume ratio: 5.3)

Modular Column Design

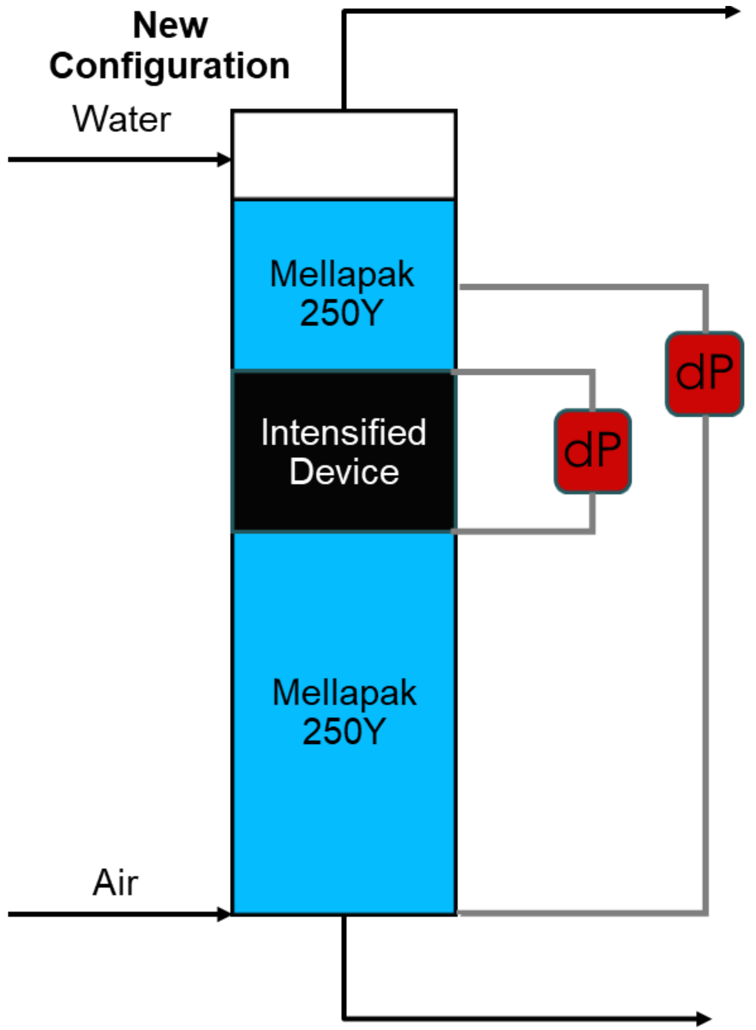


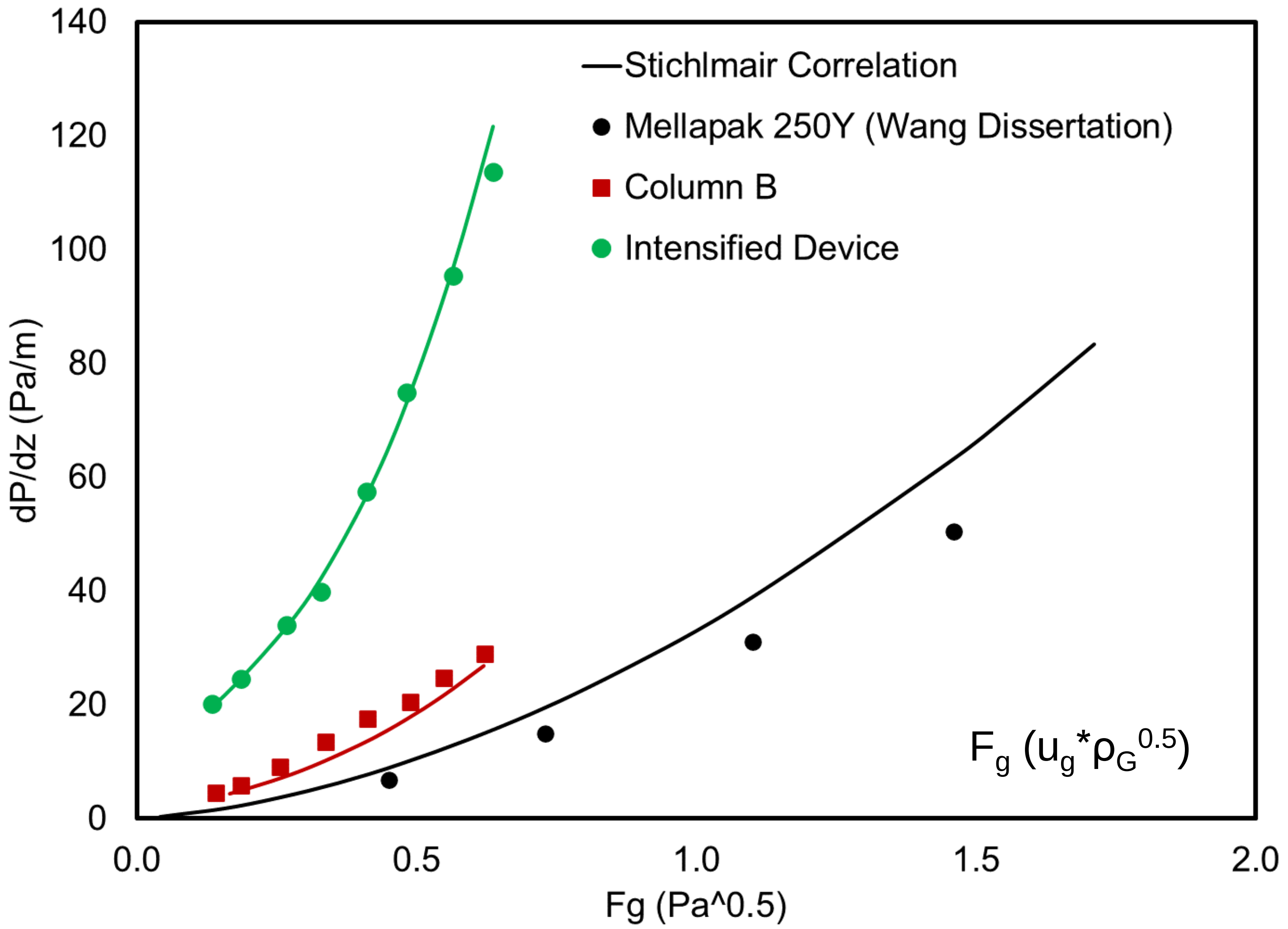
Two Sulzer Mellapak 250Y packing elements per each module

Oak Ridge National Laboratory

Modular column design provides flexibility in testing packing locations

Core Metrics Testing of Intensified Device: Pressure Drop





Pressure drop along the intensified device is relatively high

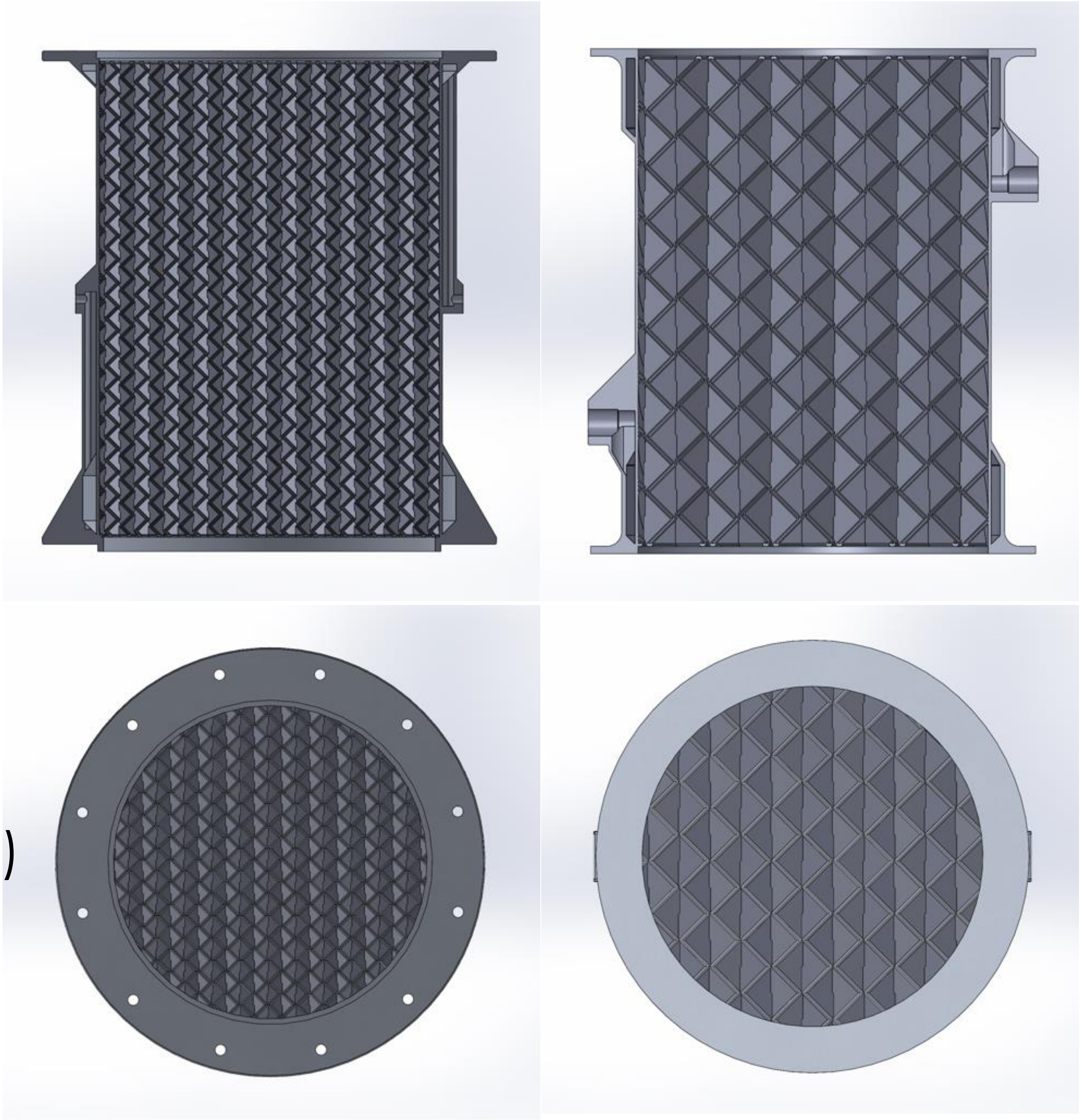
Design Revisions for Intensified Device

- Changes to reduce pressure drop
  - Increased channel width
  - Increased triangle height
  - Increased void fraction

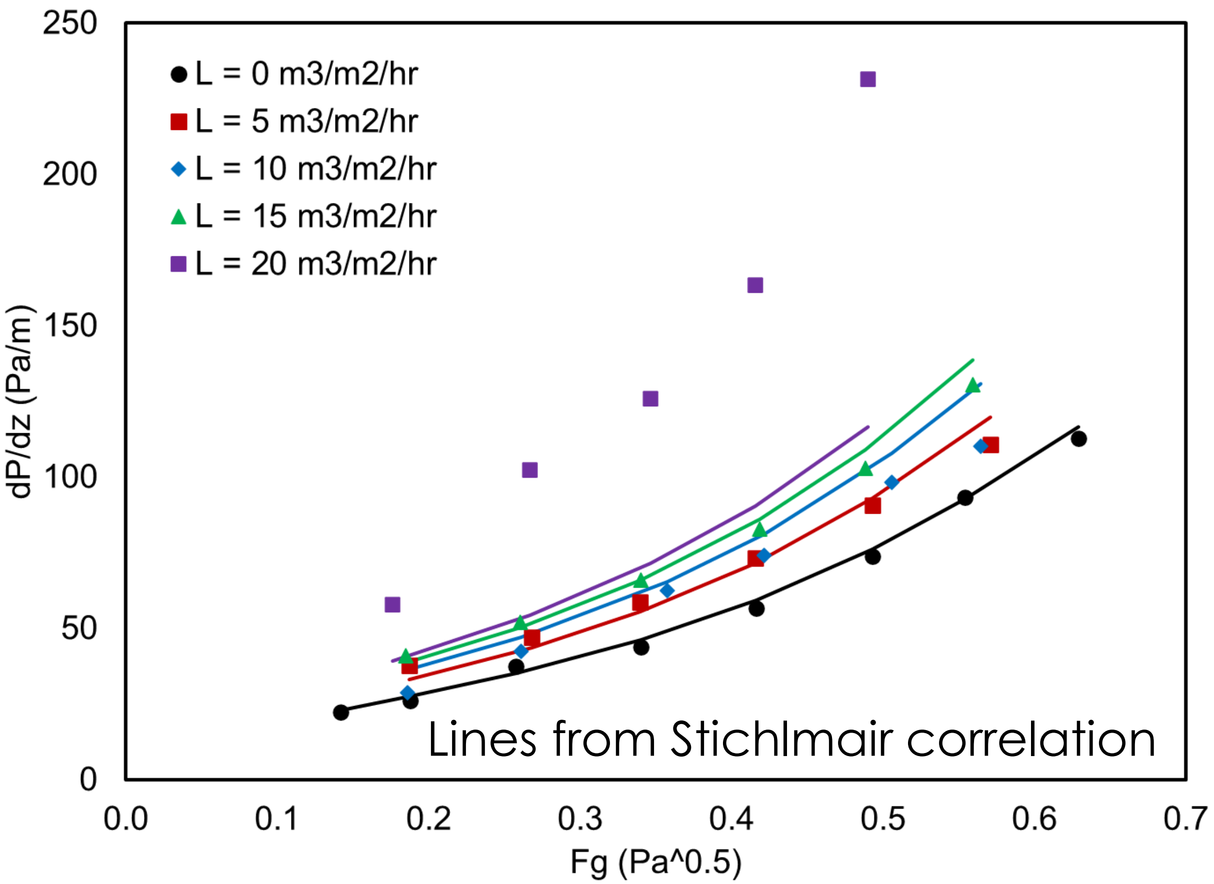
	Void Fraction
Before	60.0%
After	81.7%

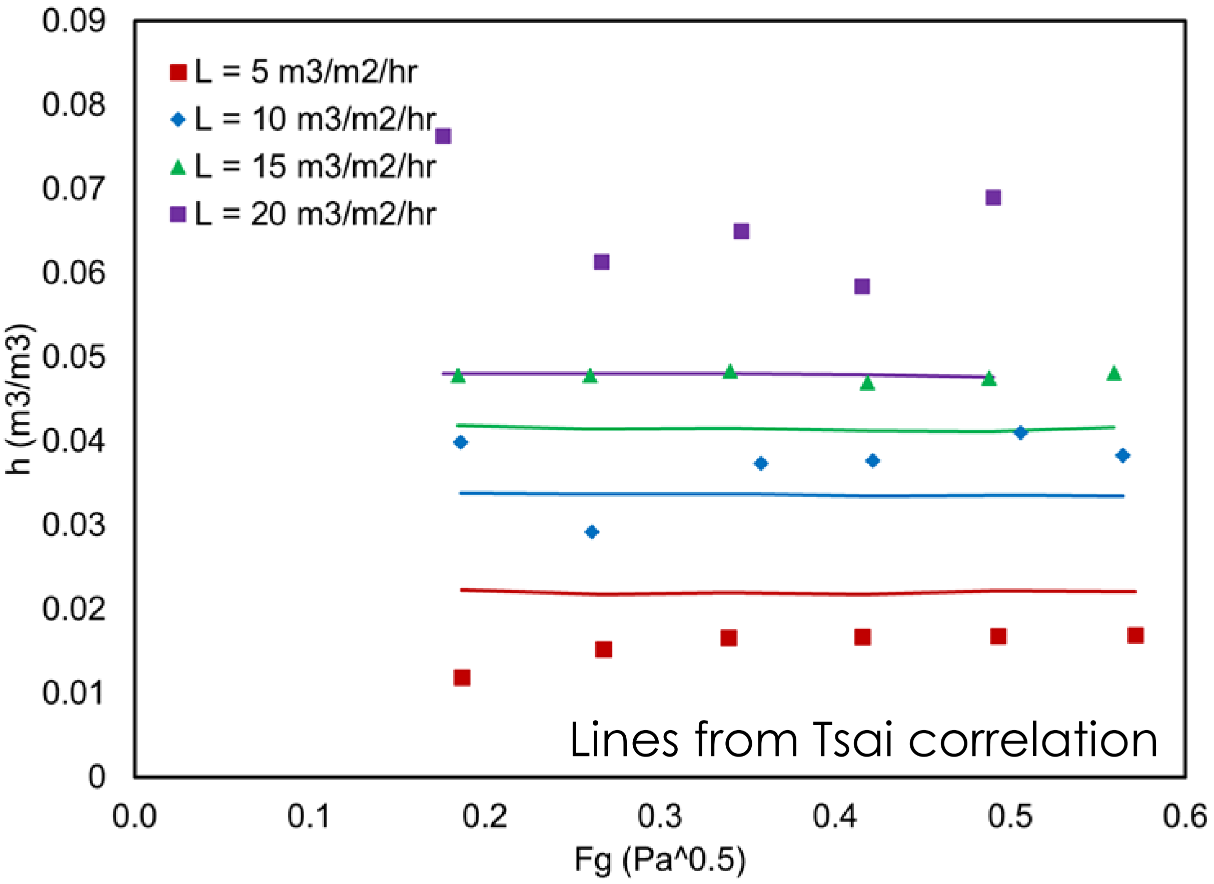
- Collaborating with CCSI2 (Panagakos) for further optimization of the device geometry

Before **After**



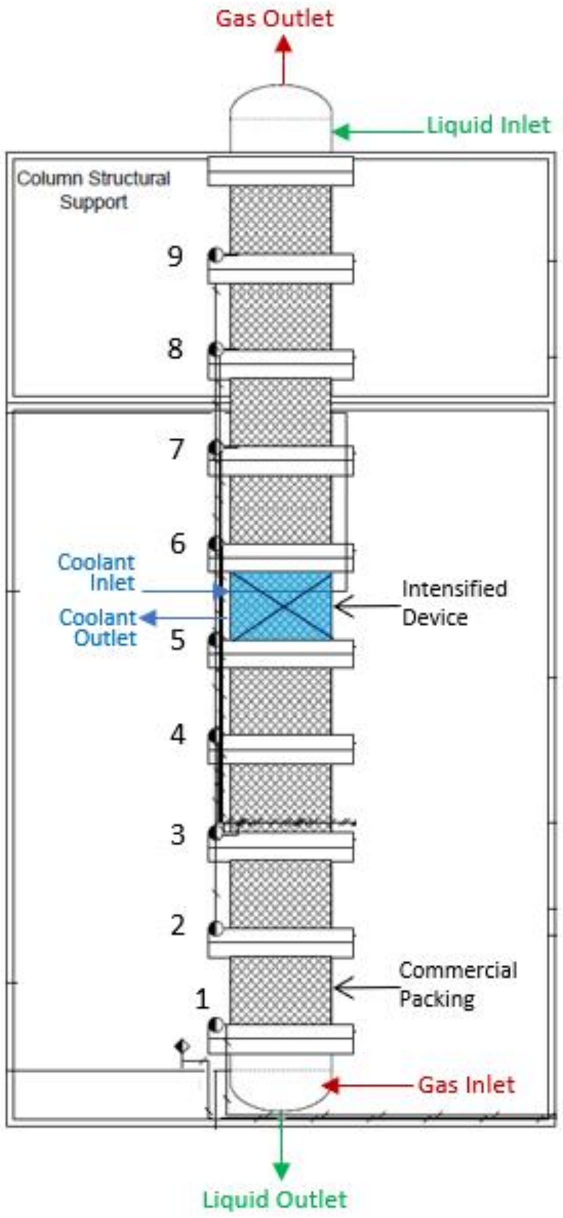
Core Metrics Testing of Intensified Device: Pressure Drop and Holdup vs F_g for Different Liquid Flowrates

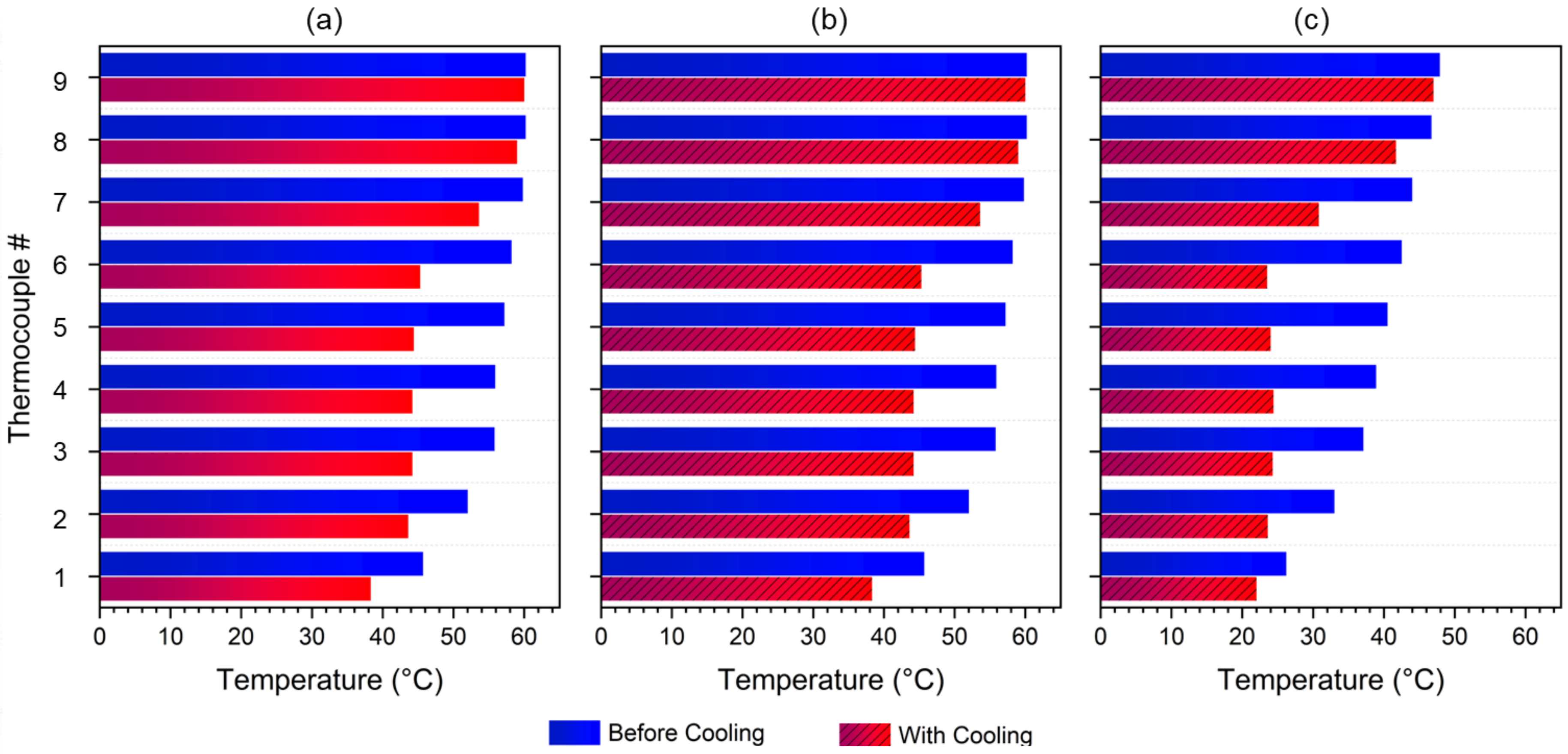




Pressure drop and holdup increase sharply near flooding

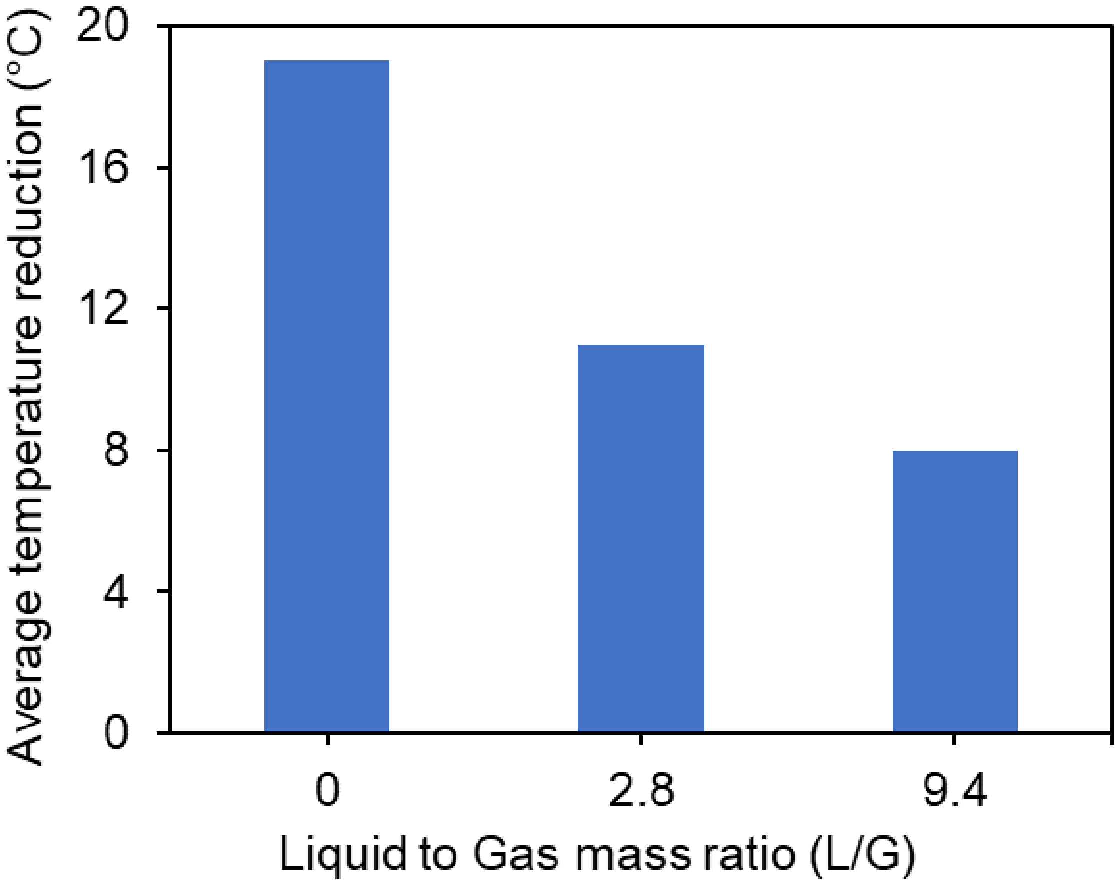
Core Metrics Testing of Intensified Device: Heat Transfer



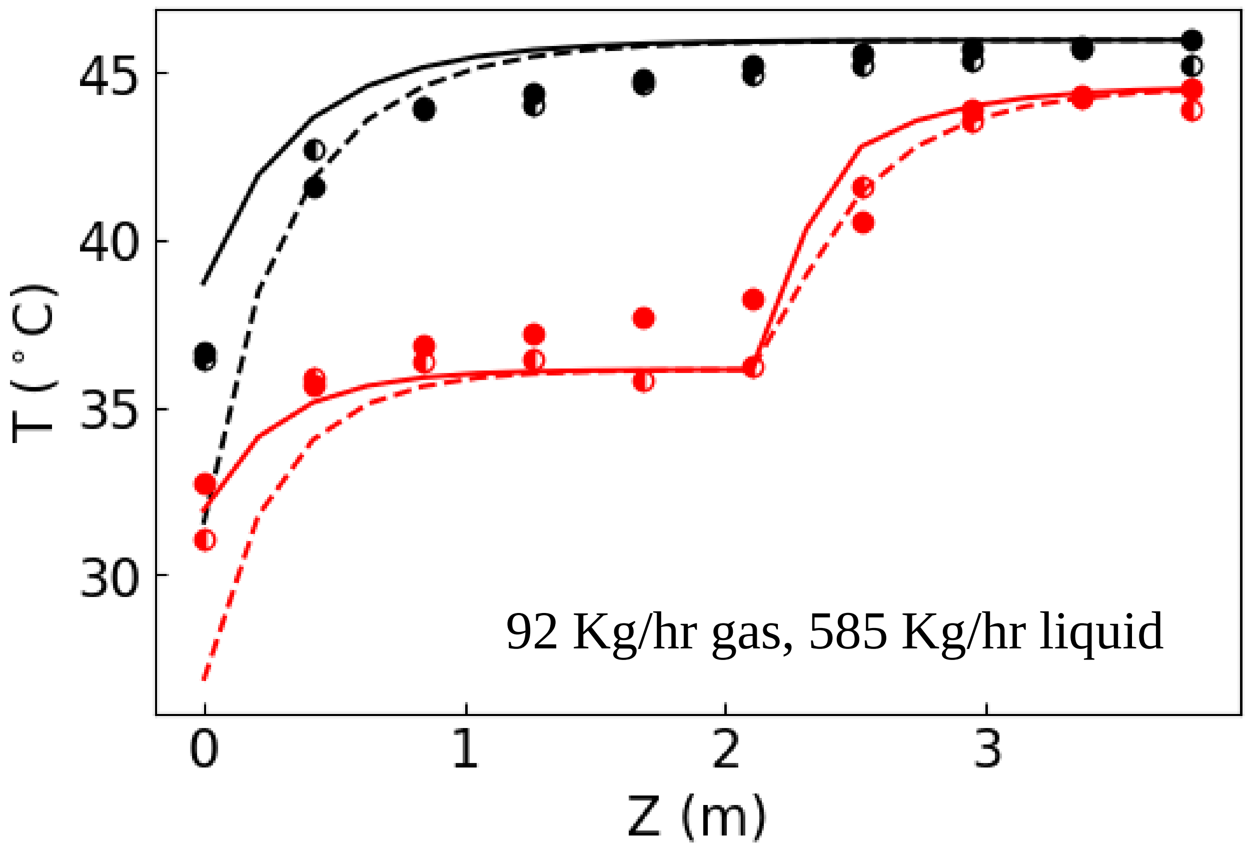


(a) Water flowrate 5 LPM, zero air flow
(b) Water flowrate 16.8 LPM, air flowrate 1500 LPM
(c) Water flowrate 5 LPM, air flowrate 1500 LPM.
Feed water temperature is 60°C and feed air temperature is 25°C in al cases

Core Metrics Testing of Intensified Device: Heat Transfer



Average temperature reduction via cooling through intensified device at liquid-to-gas mass-flowrate ratios: L/G = 0, 2.8, and 9.4



Heat transfer experiments without cooling (black) and with cooling using 2.95 L/min water at 20 C (red). Lines represent simulation results

Task 4.0 – Using NTRC Engine Combustion Exhaust to Simulate Various Flue Gas Compositions

- Feed gas will be generated with natural gas generator set
  - 100 kW generator
  - 9L natural gas engine
  - Electricity dissipated by load bank
- Exhaust gas generation:
  - Up to 1.4 tons CO_2/day
  - Water dew point and temperature managed by heat exchangers

Genset installed in the Mezzanine area

Load bank installed in the Mezzanine area

Summary

- Modeling work was used for column design
- Column construction and hydraulic & heat-transfer testing completed
- Project delays related to (1) safety incident and (2) personnel changes
- Mass transfer milestones are the focus of current work
  - CO_2 capture experiments using aqueous MEA
  - CO_2 capture experiments using LAS (RTI)
  - Performance evaluation under transient conditions

Tasks 6-9

Commercialization

- Currently helping RTI demonstrate enhanced CO_2 capture from a cement plant using intensified packing devices (AMMTO funded project)
- Plan to demonstrate further scalability in a future project

Products from FEAA384

- Thompson, Tsouris, "Rate-Based Absorption Modeling for Post-Combustion CO_2 Capture with Additively-Manufactured Structured Packing", *Ind. Eng. Chem. Res.*, **60**, 14845, (2021). https://doi.org/10.1021/acs.iecr.1c02756
- Tarancon, A., et al. "2022 Roadmap on 3D Printing for Energy," *JPhys Energy*, **4**, 011501 (2022). https://doi.org/10.1088/2515-7655/ac483d
- Lai et al. "Multifunctional Intensified Reactor Device with Integrated Heat and Mass Transfer," **Patent # 11,504,692 B2** (2022).

Acknowledgments

- Office of Fossil Energy and Carbon Management
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- David Lang and Justin Brown of NETL

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THANK YOU