FWP-FEAA130

Additively Manufactured Intensified Device for Enhanced Carbon Capture

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Energy and Transportation Science Division

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Additively Manufactured Intensified Device for Enhanced Carbon Capture

- Background:
  - Traditional solvent-based capture process and equipment:
    - Mass exchange reaction column
    - Exothermic reaction leads to thermal bulge in column, lower capture efficiency
  - Decoupled stages with external cooling:
    - High equipment and space cost
- Objective:
  - Design, rapid prototyping, demonstration and validation of enhanced CO_2 capture with *intensified devices*
    - Unified devices combining multiple thermodynamic operations into one unit: heat exchanger + mass exchanger

- **Printed heat exchangers** - Heat exchanger is one of the main applications of additive manufacturing
- Complex fluid passages, not limited to tubular structures

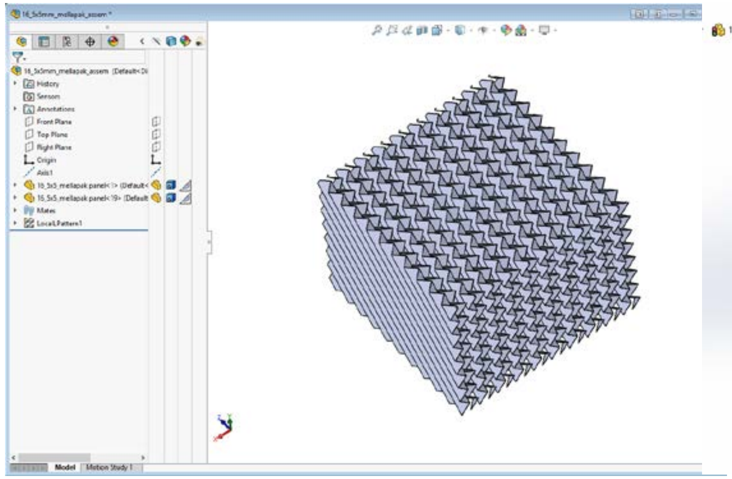
Complex fluid passages

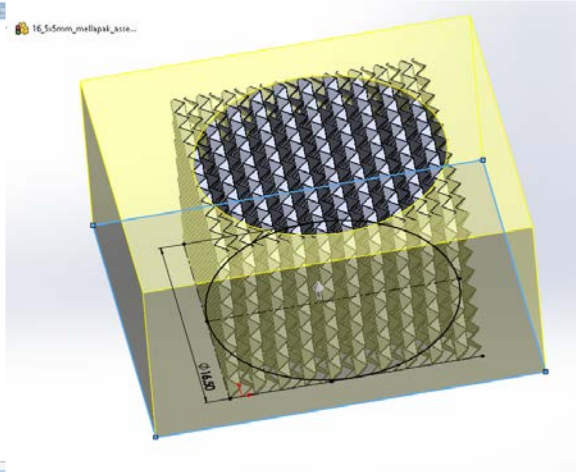
Conformal, non-circular internal passages

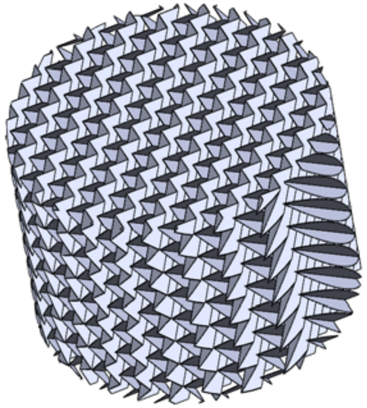
Project Overview – Two-year effort ending 9/30/2019

- Task 1.0 – Project Management and Planning
- Task 2.0 – Design Realization of Intensified Device
- Task 3.0 – Manufacturability (3D Printability) Study
- Task 4.0 – Experimental Validation of Device Core Metrics
- **Task 5.0 – Advanced Manufacturing of Device-scale Prototype**
- **Task 6.0 – Device-scale Validation through Design of Experiments**
  - Set up an experimental facility that can be used to test the heat- and mass-transfer behavior of the intensified device
  - Obtain pressure-drop data for the intensified packing device
  - Obtain heat-transfer data and compare with modeling results for a nonreactive system (water-air)
  - Obtain heat- and mass-transfer data for the CO2-MEA reactive system; experiments guided by modeling

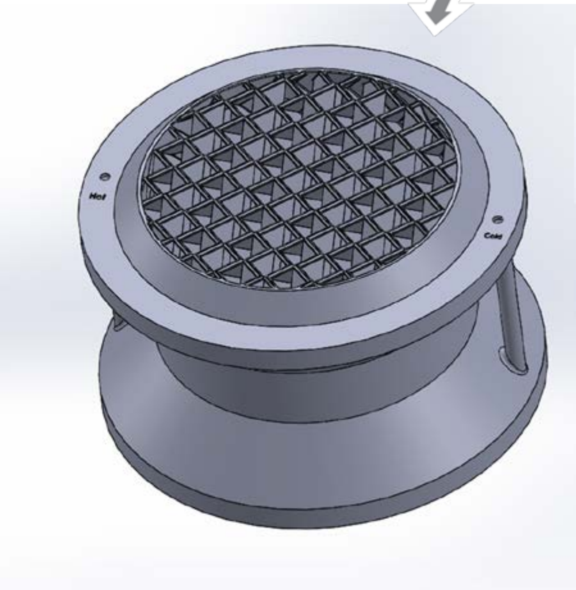
Manufacturability (3D Printability) of 2nd Gen Int. Device

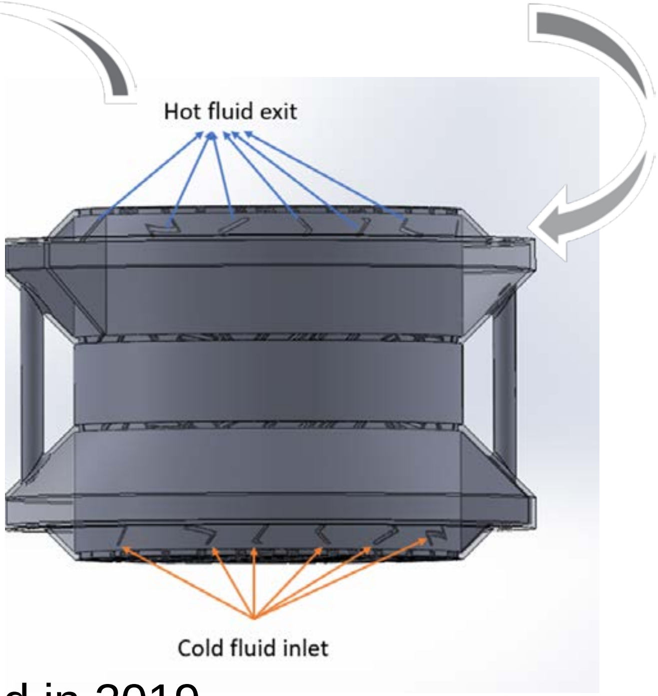






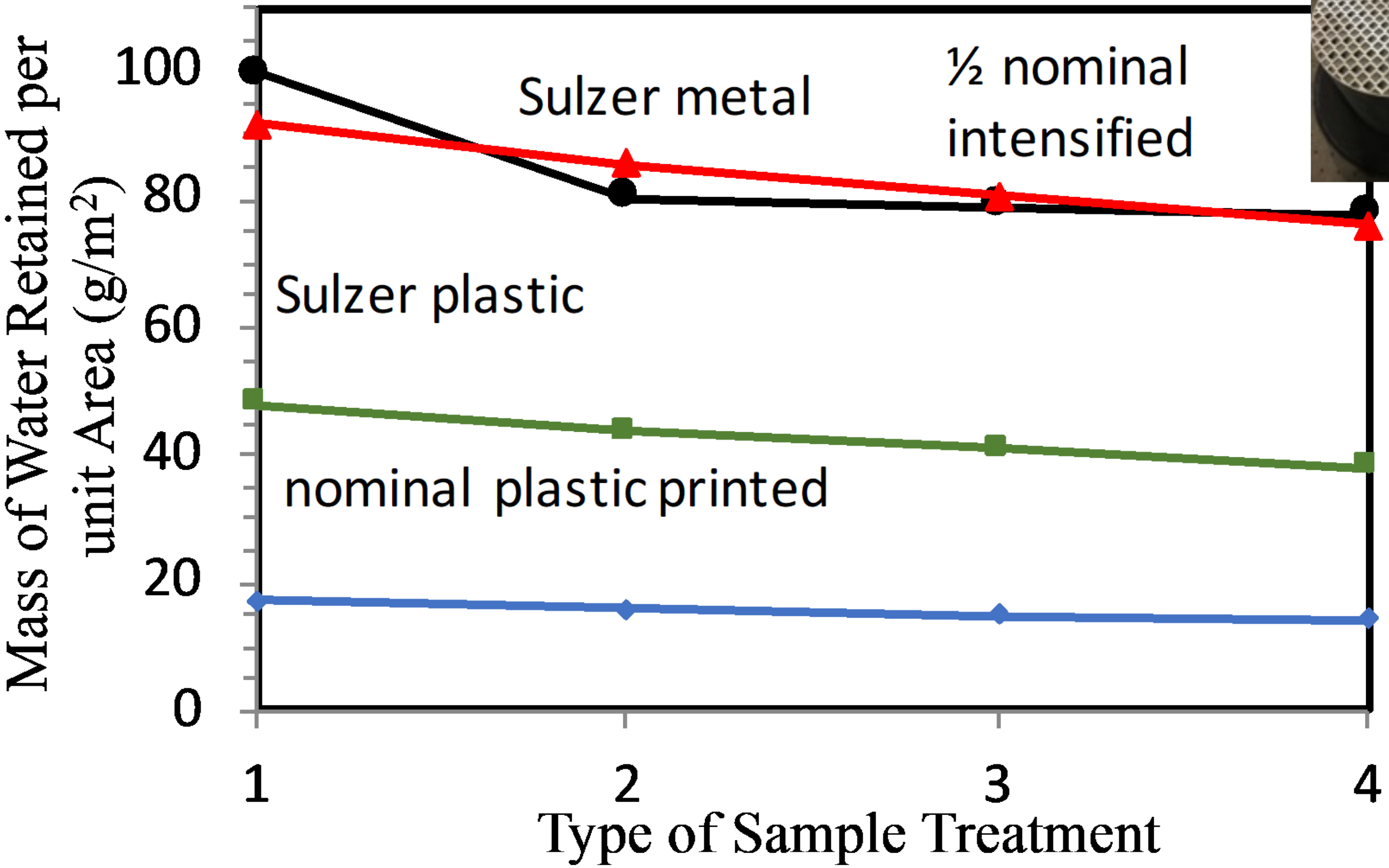
Total Baffle area (m2)	10.23
Cylinder area (m2)	0.406
Total area (m2)	9.824
Material volume (m3)	0.004365
Diameter (m)	0.424
Height (m)	0.3048
volume (m3)	0.043015
Area/volume	228.3873
Volume/volume	0.101477





2nd generation intensified devices printed in 2019

The Printed Aluminum and Sulzer Metal Packing Devices Shows Similar Water Mass Retained



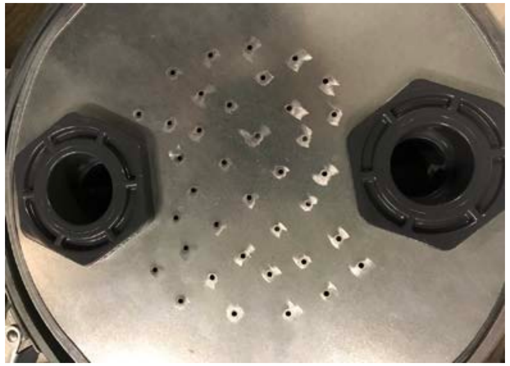
Experimental Facility for Column Scale Testing

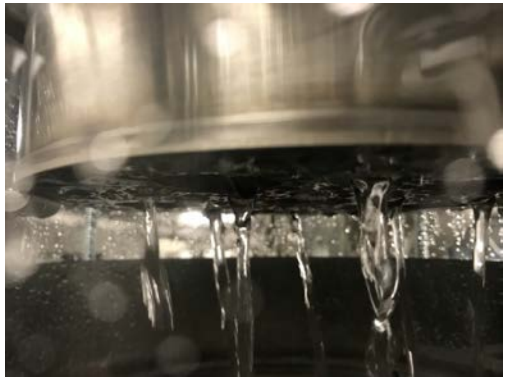
Stainless-steel and plastic Sulzer Mellapak 16-inch diameter packing elements (Thanks to Dr. Gary Rochelle)

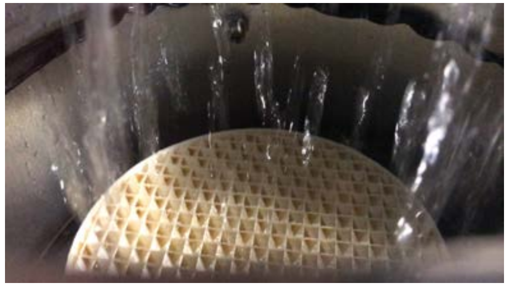
A column was first set up to compare the hydraulic performance of commercial packing materials with 3D printed packing devices manufactured in this project

Column for Testing 8-inch Diameter Packing Elements

Air pump providing over 4,000 LPM

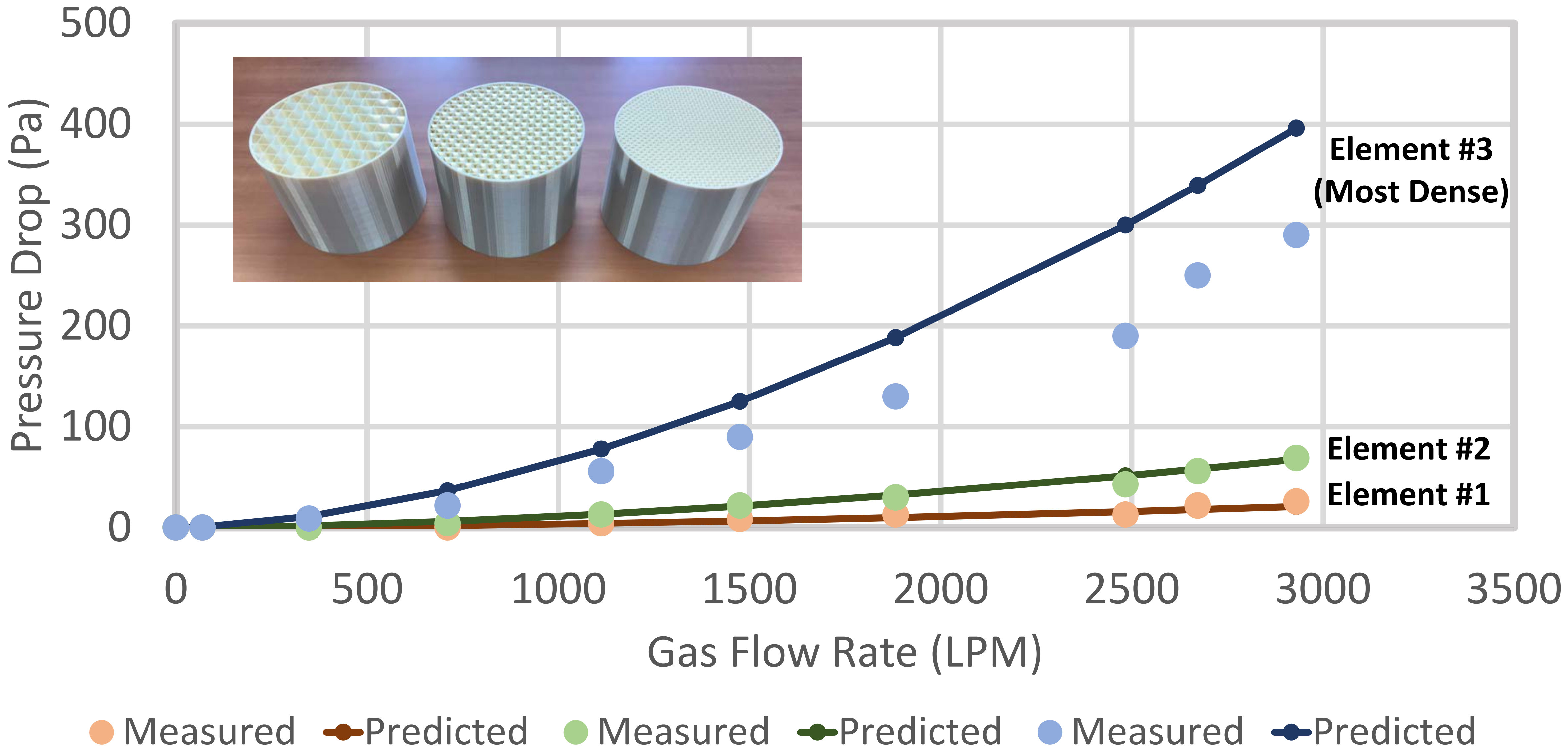




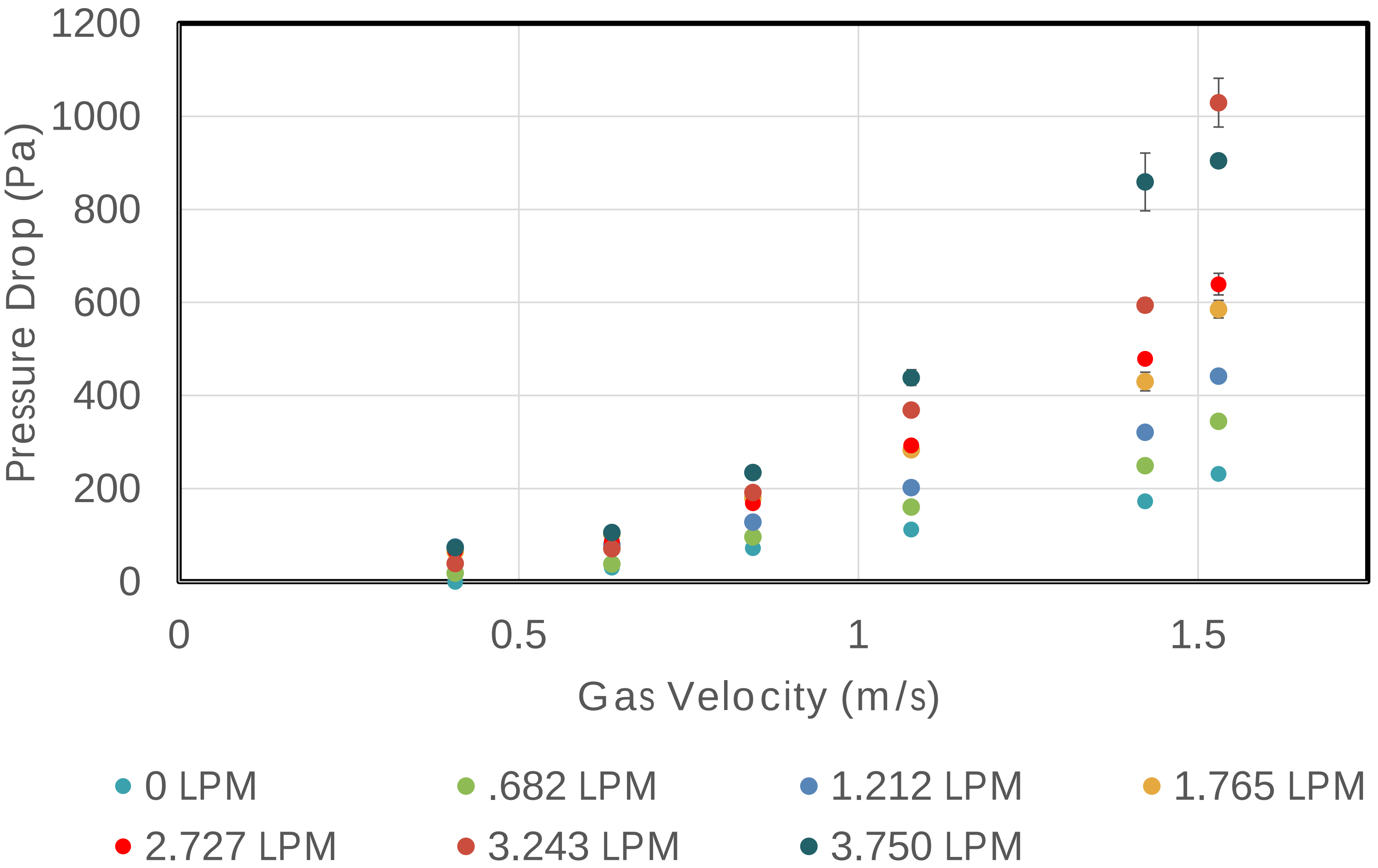


Stephen Bolton
Chemical Engineer Student
University of Delaware

Measured dry Pressure Drop for 8” Printed Packings



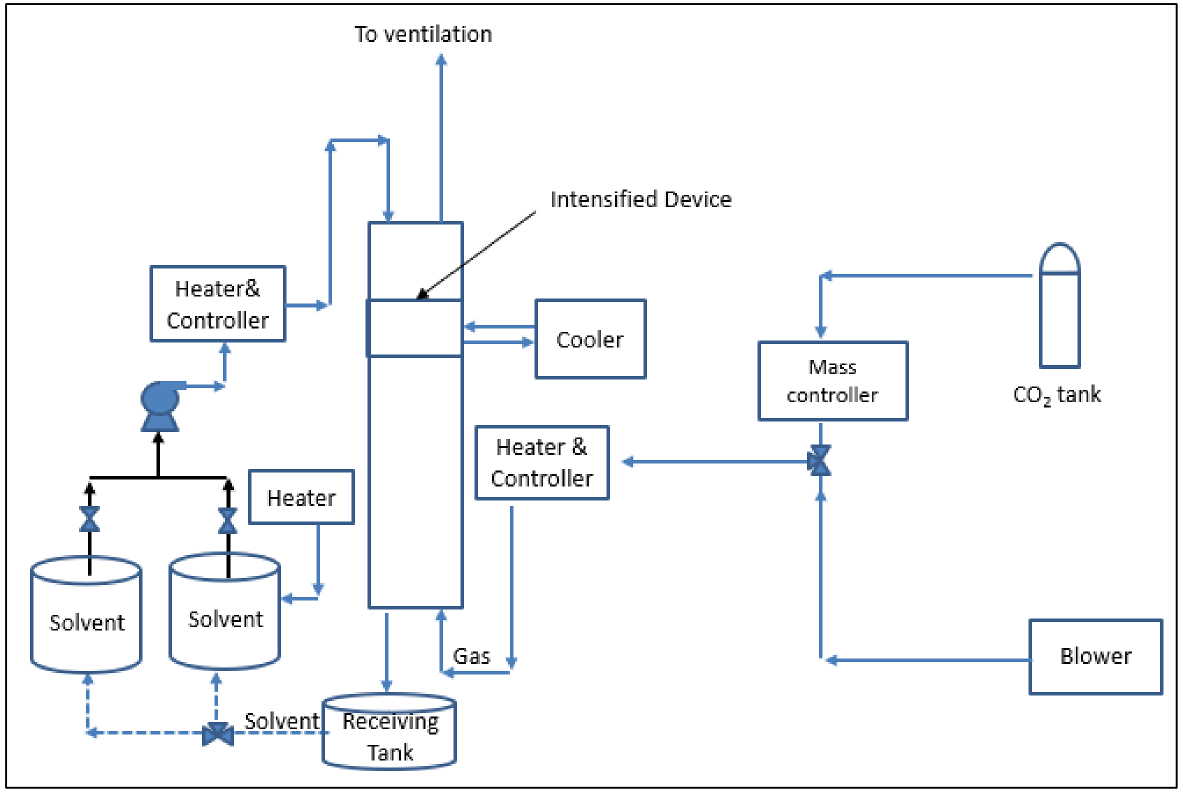
Pressure Drop Measurements vs Gas Velocity for the Irrigated System with the Intensified Device



- 3D printed device behaves similarly to commercial devices for pressure drop

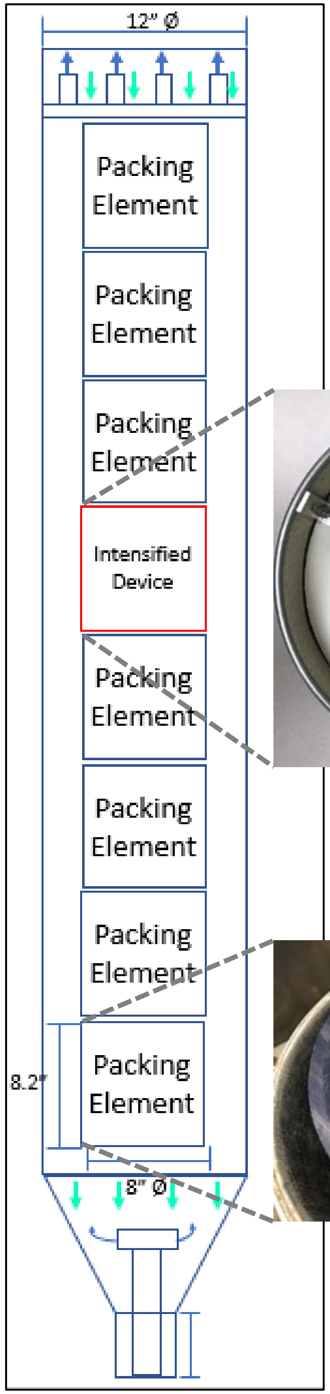
Column Scale Validation of Intensified Device

- **Overview**
  - The system's primary task is to deliver a gas mixture of adjustable CO_2 concentration and aqueous MEA in counter-current flow to an absorption column comprised by packing elements at controlled temperatures
- **Mass Flow Control**
  - Required composition is achieved by controlling flowrates of constituent gases
- **Temperature Control**
  - Gas and solvent will be heated to between 30 and 80 °C
  - Gas will be heated with a 3.6 kW in-line air heater
  - Solvent will be heated using a 11kW tankless water heater



Schematic of experimental system

ORNL Absorption Column for Heat and Mass Transfer Validations

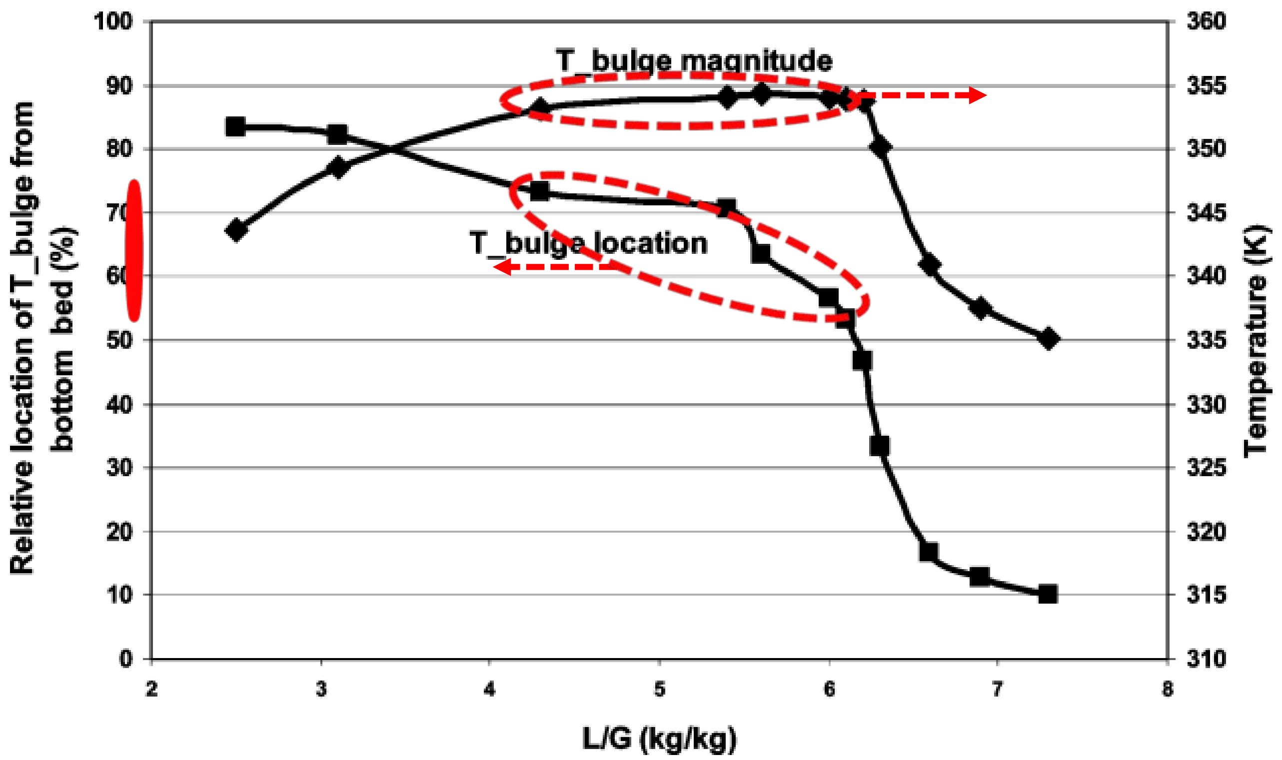


Absorption column
with packing elements

- There are 7 commercial packing elements in the column in addition to the intensified device
- The intensified device was placed after the fourth element from the bottom

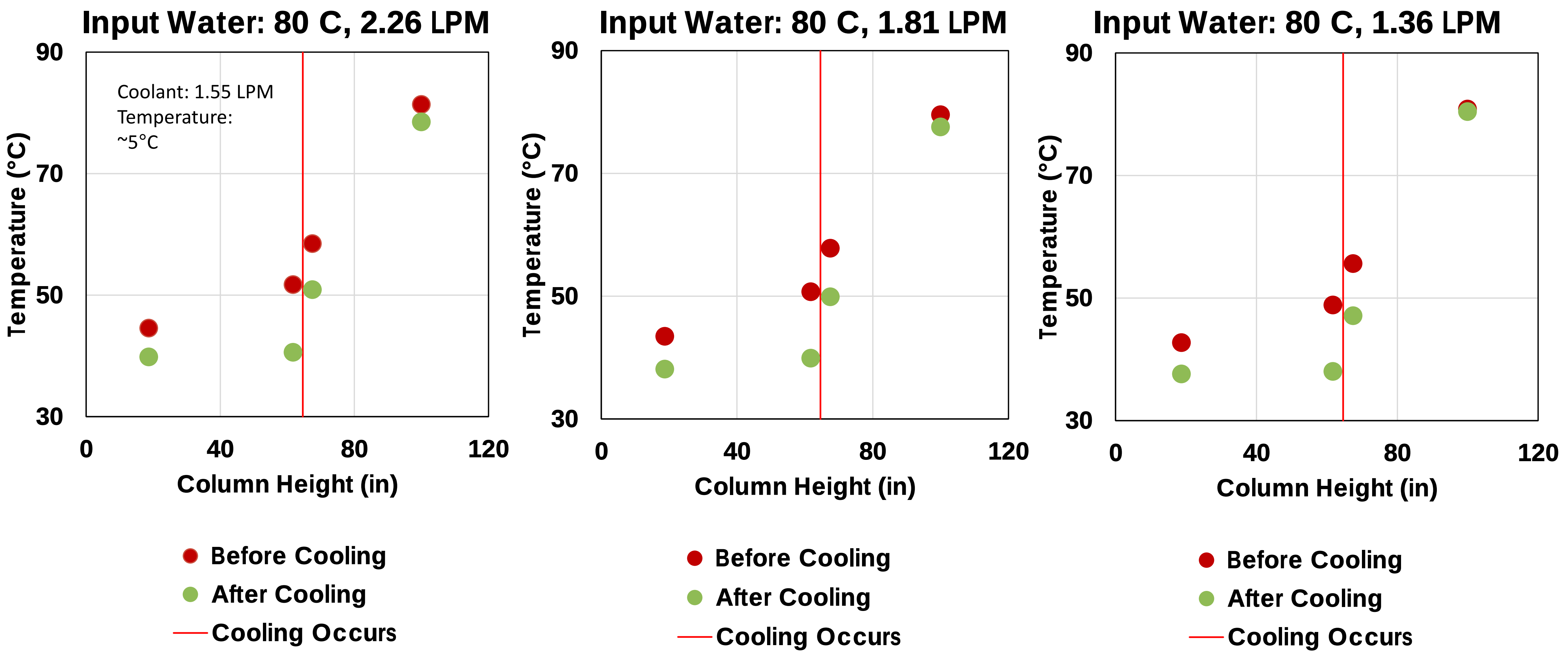
Location of Temperature Bulge Depends on L/G Ratio

- The magnitude of the bulge is maximized near the center of the column
  - At that location, there is a decrease in CO_2 absorption
  - Hypothesis: Cooling the location of the bulge could promote higher CO_2 absorption



(Kvaamsdal & Rochelle, 2008)

Heat Transfer for the Nonreactive Air/Water System: Temperature Profiles of Water (Input Air : 80 C, 650 LPM)

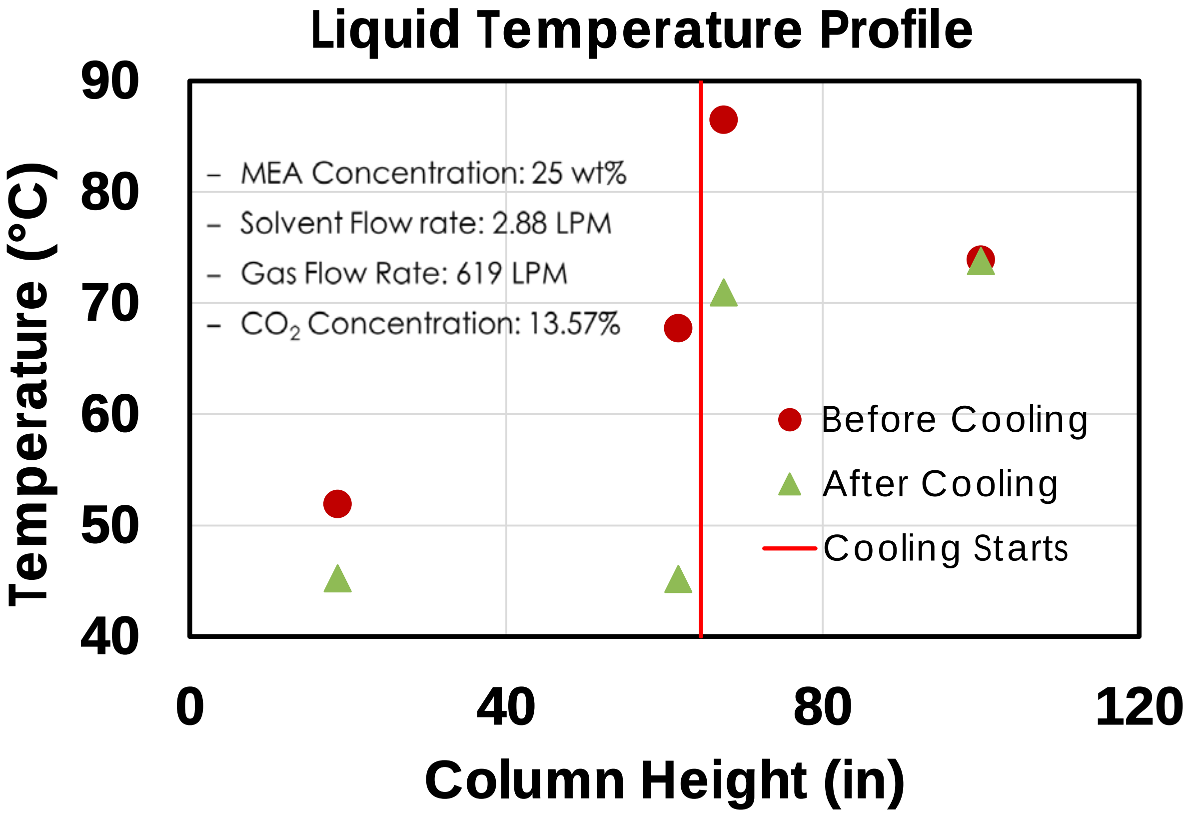


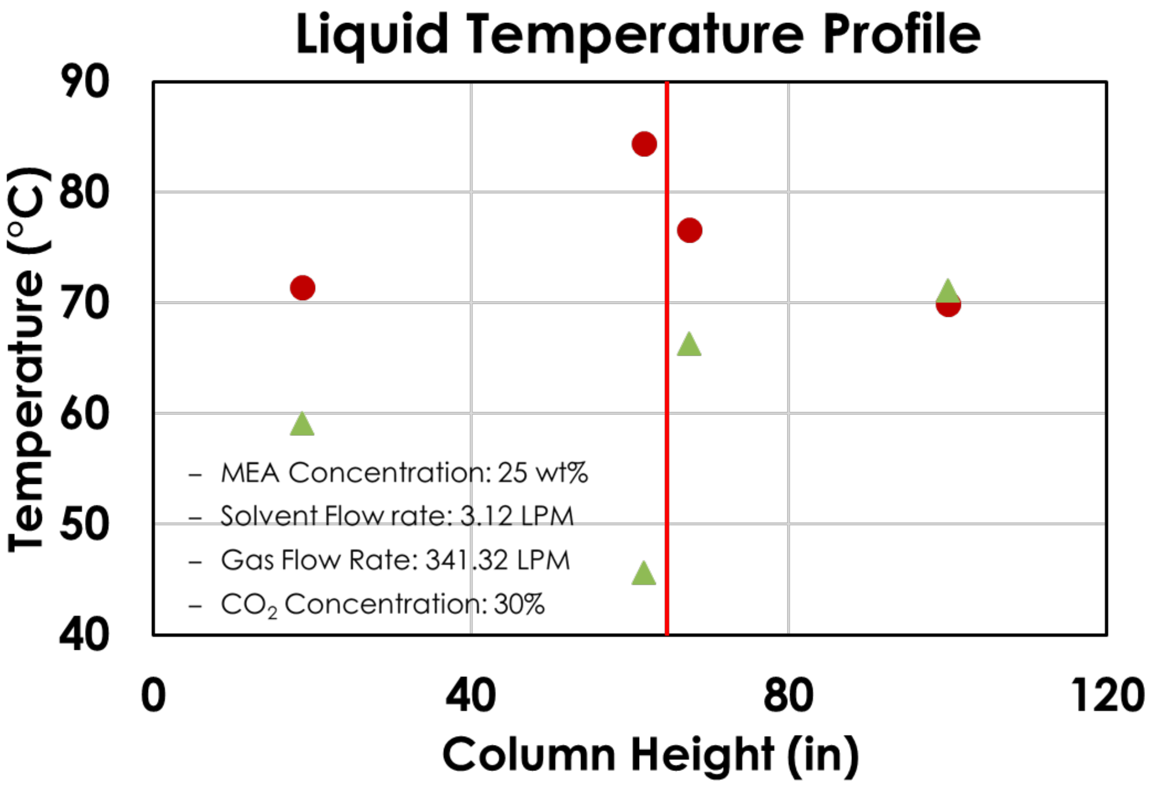
Heat Transfer Study: Average Heat-Transfer Coefficient

- Heat transfer coefficient at selected experimental conditions
- Calculated heat transfer coefficient were consistent for all conditions

Air Flow Rate (LPM)	Air Temperature (°C)	Water Flow Rate (LPM)	Water Temperature (°C)	Heat-Transfer Coefficient (W/K-m2)
650	80	1.36	80	34.7
650	80	1.81	80	34.7
650	80	2.26	80	32.8
650	80	2.26	60	32.8
650	80	2.26	40	32.5
520	80	2.26	80	34.9

Reactive MEA-CO_2 System: Identify T bulge location



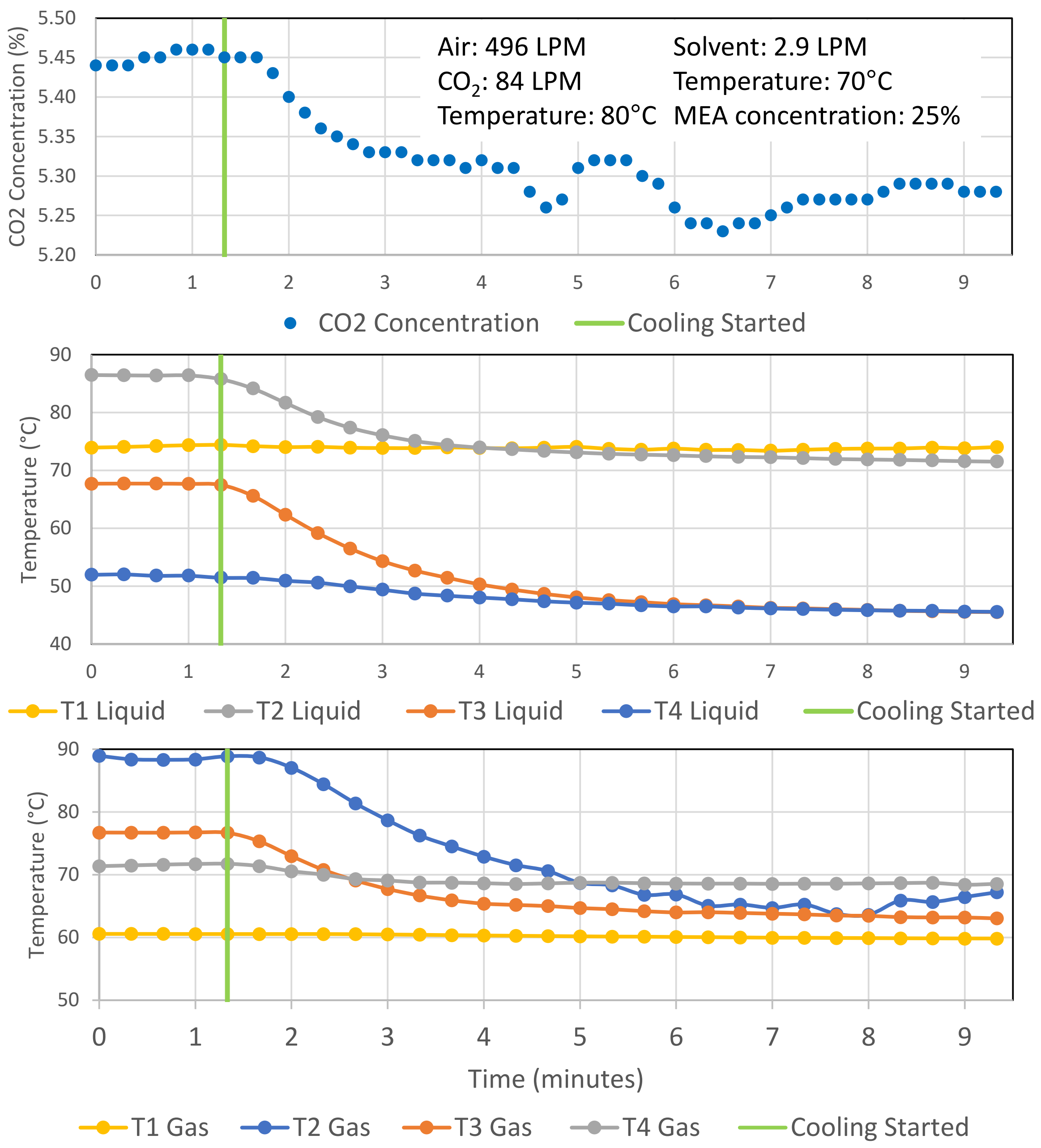


Experimental Conditions:

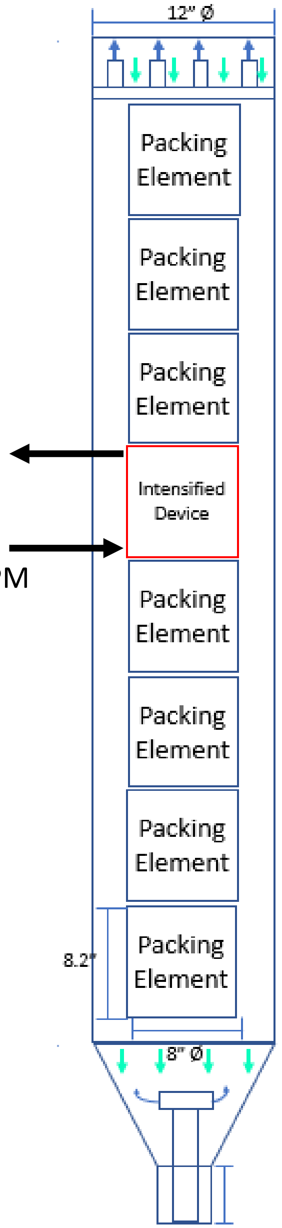
- A lower L/G ratio was needed to move the temperature bulge to the middle

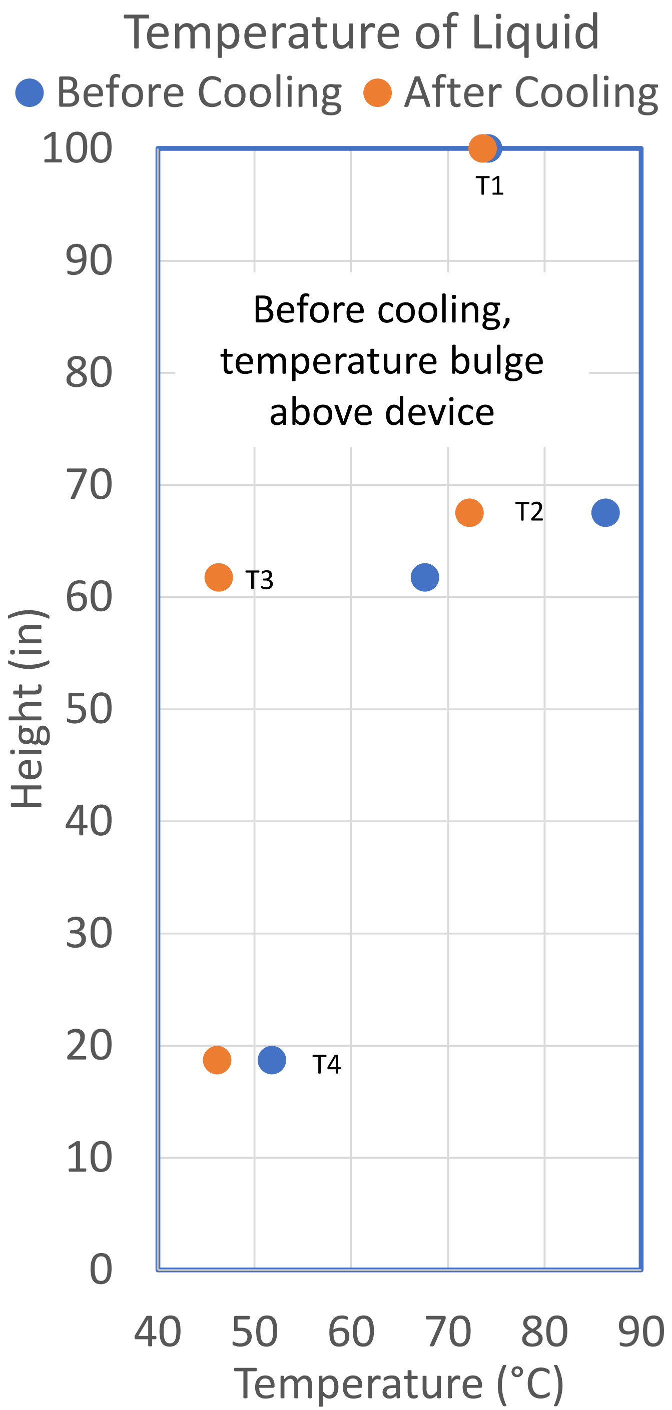
Oak Ridge National Laboratory

Cooling Effect on CO_2 Capture

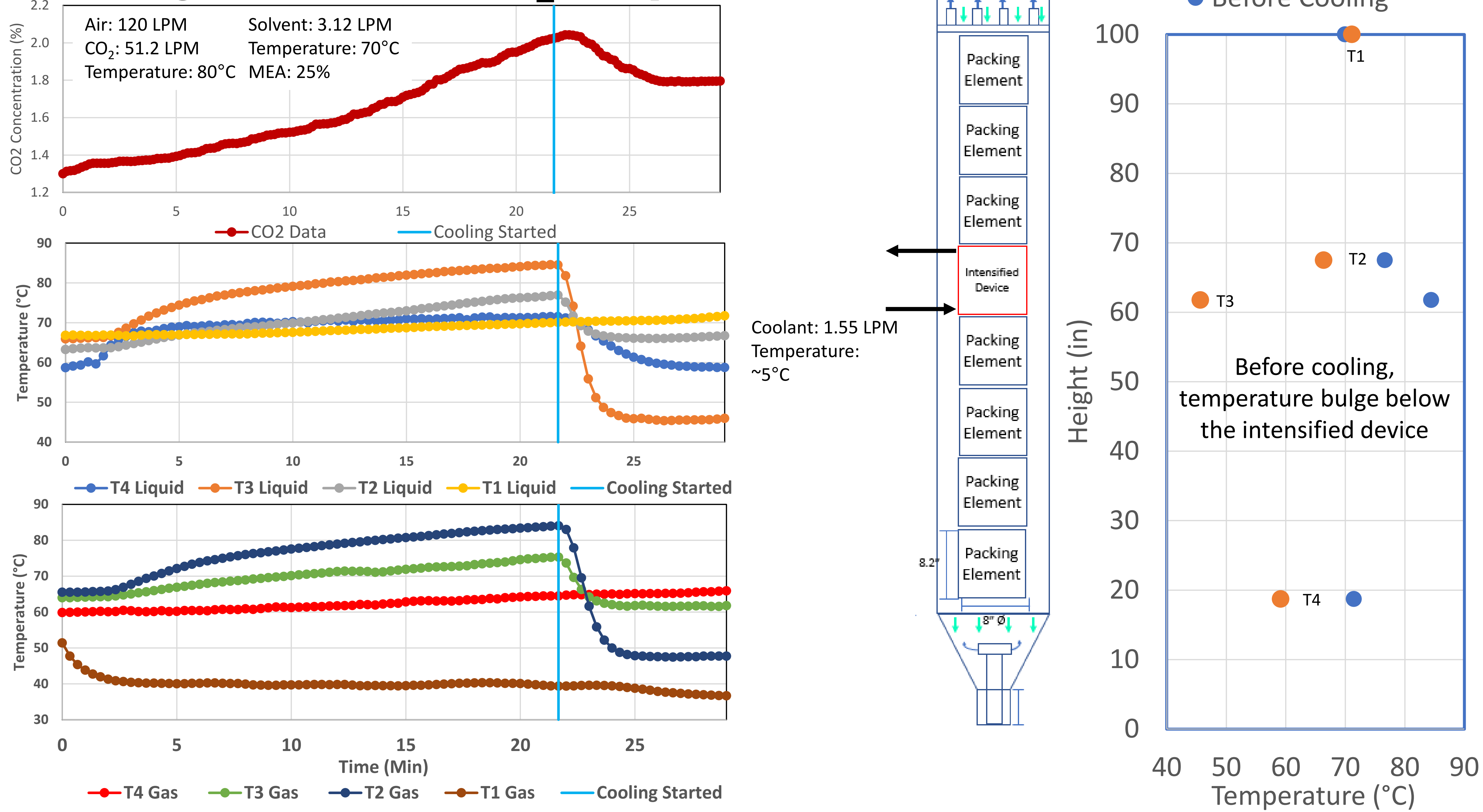


Coolant: 1.55 LPM
Temperature: ~5°C

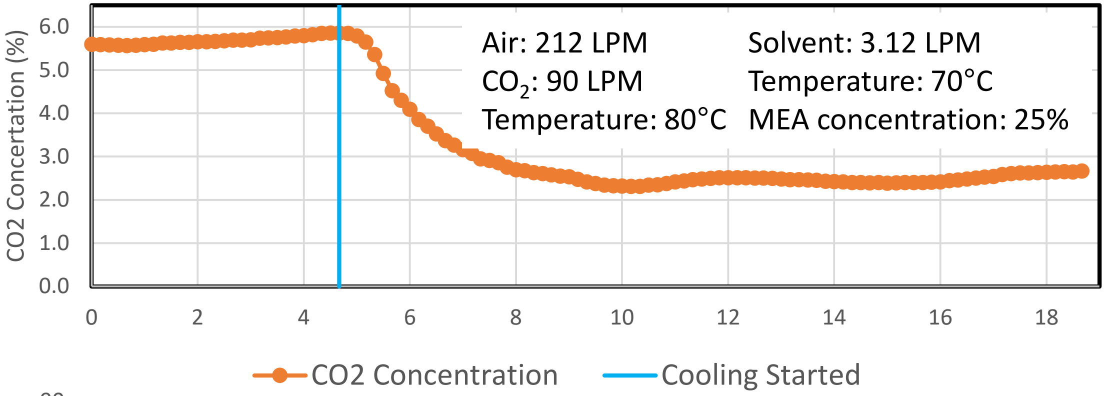


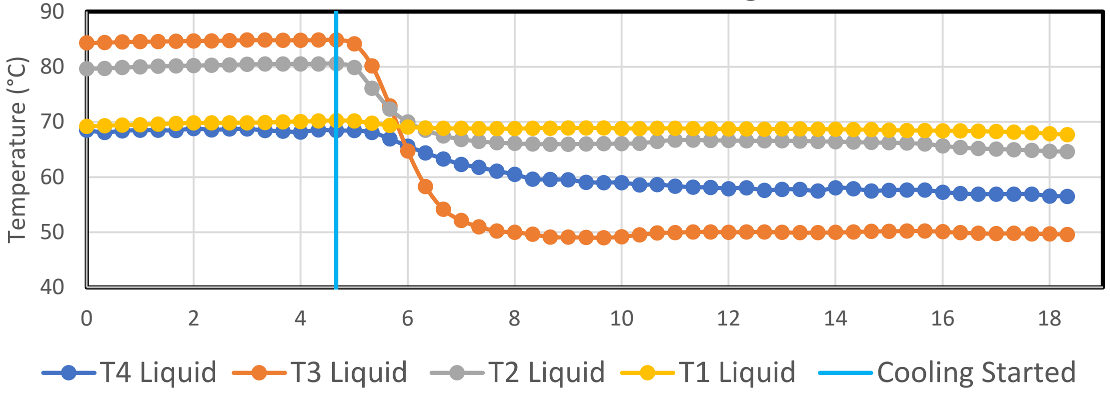


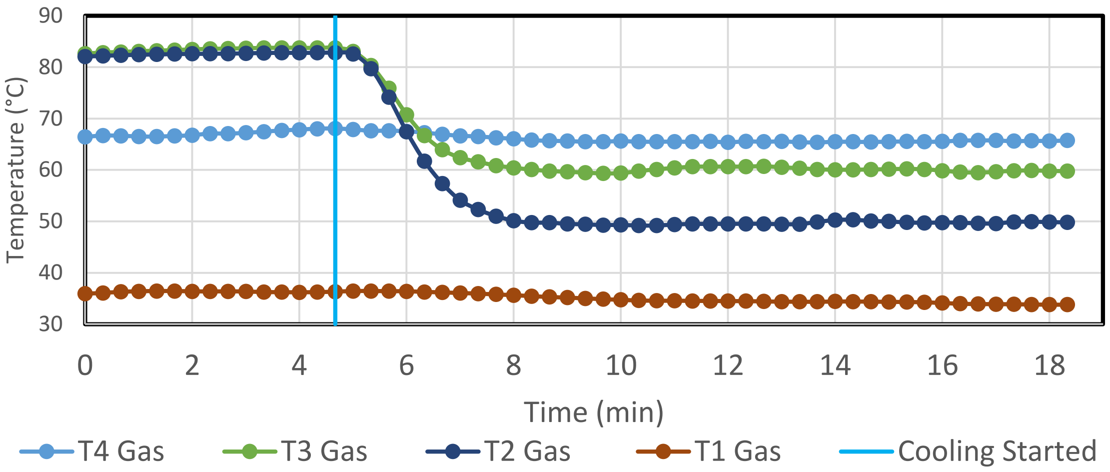
Cooling Effect on CO_2 Capture



Cooling Effect on CO_2 Capture

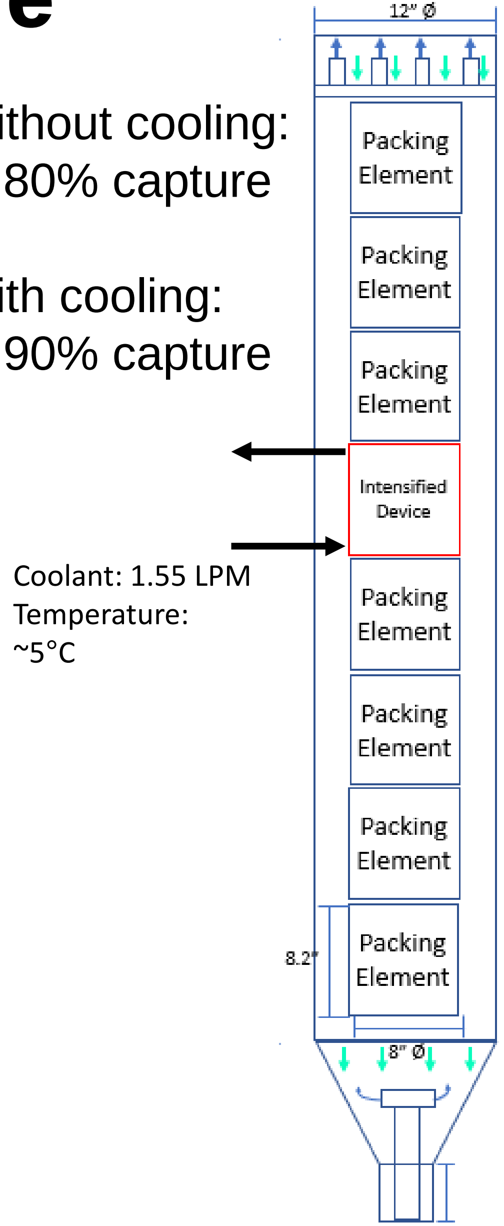


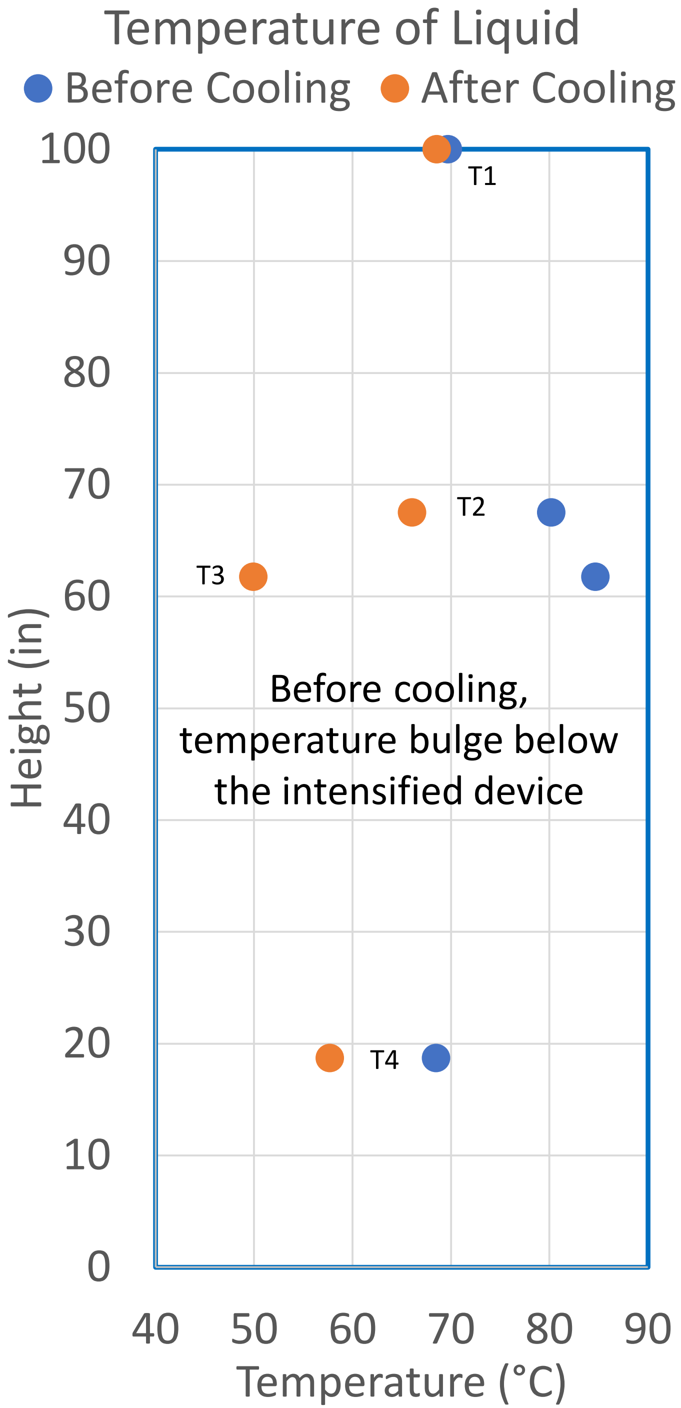




Without cooling:
80% capture

With cooling:
90% capture





Conclusions and Accomplishments

- **Conclusions**:
  - Validated the enhanced CO_2 capture of intensified device
- **Accomplishments:**
  - Submitted Invention Disclosure 201804270, DOE S-138,941, and provisional patent application: “Multifunctional Intensified Reactor Device with Integrated Heat and Mass Transfer”
  - Manuscript published: Bolton, S.; Kasturi, A.; Palko, S.; Lai, C.; Love, L.; Parks, J.; Sun, X.; Tsouris, C. “3D Printed Structures for Optimized Carbon Capture Technology in Packed Bed Columns,” Separation Science and Technology, 54, 2047-2058 (2019)
  - Manuscript in internal review: Miramontes, E.; Love, L.; Lai, C.; Parks, J.; Sun, X.; Tsouris, C. “Additively Manufactured Packed Bed Devices for Process Intensification of CO_2 Absorption and Other Chemical Processes”
  - In discussions with Sulzer Chemtech Ltd, which produces packing elements for packed columns, toward commercialization of the intensified device