“Rapid Design and Testing of Novel Gas-Liquid Contacting Devices for Post-Combustion CO_2 Capture via 3D Printing”
Modular Adaptive Packing (MAP)

DE-FE0031530 – NETL Project Review Meeting Pittsburgh

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Agenda

- Background
- Project Overview and Objectives
- Design Results through CFD
- 3D Printing

ION's CO_2 Capture Technology Development

ION is developing its technology by leveraging existing research facilities

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2010

ION Engineering Lab-pilot
0.01 MWe, $4M
Boulder, CO, USA

2012

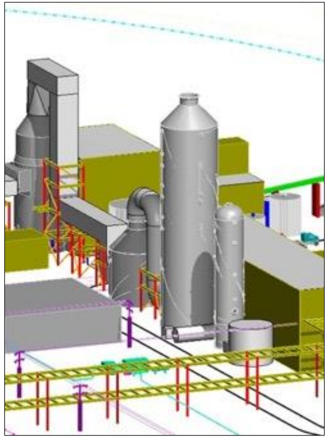
Univ. of N. Dakota EERC
0.1 MWe, $2M
Grand Forks, ND, USA

2015

National Carbon Capture Center
0.5 MWe, $10M
Wilsonville, AL, USA

2016 - 2017

CO_2 Technology Centre Mongstad
12 MWe, $15M
Mongstad, Norway

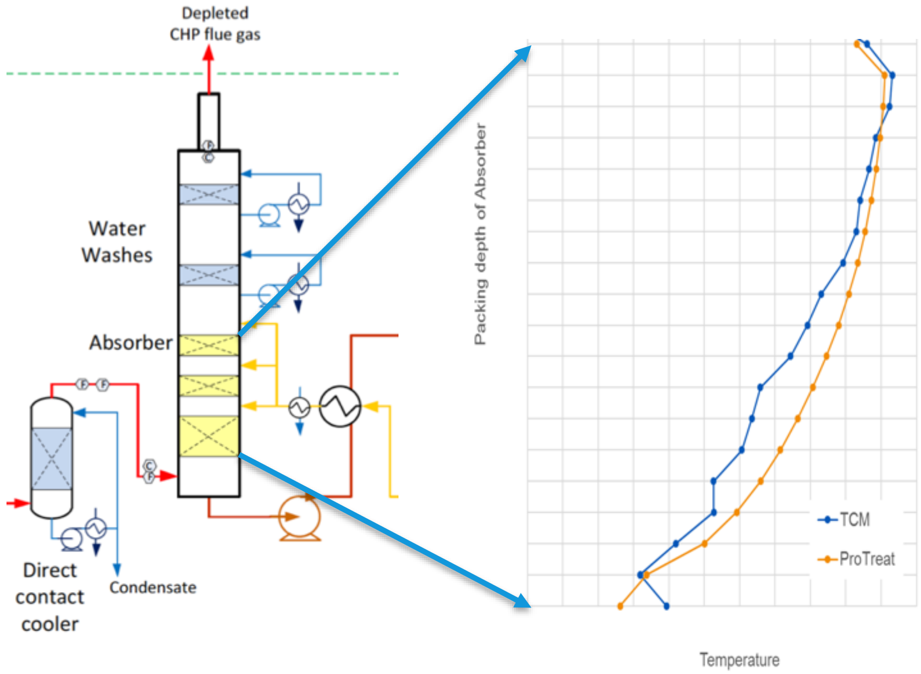


2018 - 2019

Design & Costing Commercial Retrofit
300 MWe
Sutherland, NE, USA

Background

High Temperature Bulge for Fast, Low Heat Capacity Solvents



Source: Thimsen et al., GHGT-12, 2014

ION Campaign at TCM (2016-17)

- Testing operating window was limited by absorber materials (T_{max})
- Additionally, temperature bulge affects emissions and degradation reactions
- Hence, how can we incorporate in-situ cooling throughout the absorber column?

Background

“Rapid Design and Testing of Novel Gas-Liquid Contacting Devices for Post-Combustion CO_2 Capture via 3D Printing”

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ION has initiated the development of an innovative internal absorber design including distributor, mass transfer, heat exchange and collectors through additive fabrication techniques

The application of 3-D printing is to significantly reduce the costs of such columns

- Accelerates the design cycles of gas-liquid contacting devices
  - Design process is entirely software-based
  - Devices are parametrically engineered
  - Rapid and flexible feedback loop between design, fabrication and testing that can only be provided through 3-D printing advance more quickly the performance and lower the costs of novel gas-liquid contacting devices for CO_2 capture.
- Minimizes manufacturing costs

Project Overview

DE-FE0031530

- SBIR Phase III
  - Prior project: DE-SC0012056
- Project Period of Performance: Jan 2018 – May 2020
- $2.6M DOE-NETL project funding

- Overall Project Objective:

  Develop a 3D-printed Modular Adaptive Packing (MAP) with internal heating or cooling capabilities. Once a finalized design is complete, the packing performance will be characterized in a modified Packing Characterization Rig.

Technical Approach

Overall Project

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Budget Period 1

Jan 2018 – Nov 2019

Design & Build:

- Task 1: Project Management
- Task 2: MAP Design & Plastic Prototype Manufacture
- Task 3: Packing Characterization Test Preparation
- Task 4: MAP Metal Module Printing

Budget Period Continuation

Success Criteria:

1. Successful Printing of MAP modules in metal
2. Packing characterization rig modifications complete

Budget Period 2

Dec 2019 – May 2020

Characterize & Evaluate:

- Task 1: Project Management
- Task 5: Packing Characterization
- Task 6: Results & Final System Analysis

Technical Approach

Overall Project – Success Criteria

- Success Criteria for Budget Periods
  - Budget Period 1
    1. Successful printing of MAP modules in metal
    2. Packing characterization rig modifications complete
  - Budget Period 2
    1. Completion of packing characterization as outlined in test plan
    2. Concept evaluation report completed

Project Participants & Roles

ION CLEAN ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Funding

SULZER

Commercial Packing Supplier & Engineering Support

Process Simulation & Design

Optimized Gas Treating, Inc.

ION ENGINEERING

3D Printing & Design Support

3D SYSTEMS

MAP Module CFD Model Development

ANSYS

Project Schedule

MAP Phase III Project Schedule		Budget Period 1																							Budget Period 2					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
		Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-19	May-19
Task 1	**Project Management**	D1			M1			M2				M3									D2		D3 M4		D4		M5			D5
Task 2	**MAP Design**																													
2.1	Design basis																													
2.1	Parametric design delivered to ANSYS																													
2.1	ANSYS module developed to model physics, fluid dynamics, etc.																													
2.2	ION optimizes ANSYS model with different parameters																													
2.2	Prototype prints/evaluation																													
2.3	Fittings designed																													
2.4	Detailed analysis of prototype prints																													
2.4	Final design chosen																													
Task 3	**Host Site / Packing Characterization Test Preparations**																													
3.1	Modfications identified for test rig																													
3.2	Procurement / construction of modifications																													
3.3	Test plan development																													
3.4	Baseline packing characterization utilizing commercial packing																													
Task 4	**MAP Metal Printing**																													
4.1	Metal module printing commences																													
4.2	First metal module inspected for quality control prior to remaining modules being printed																													
4.3	Second metal module printed - quality control testing																													
4.4	Remaining modules printed																													
4.4	Delivered to test facility																													
Task 5	**Packing Characterization Testing**																													
5.1	Installation & Commissioning of MAP Modules																													
5.2	Characterization of MAP Modules																													
5.3	Decommissioning of MAP Modules																													
Task 6	**Evaluation & Reporting**																													
6.1	Process modeling & simulations																													
6.2	Data analysis & concept evaluation																													
6.3	Final reporting																													

Project Overview

Deliverables & Milestones

Deliverables

#	Corresponding Task/Subtask	Title/Description
D1	1.0	Project Management Plan – BP1
D2	2.4	Test internals final design (report)
D3	3.3	Initial test plan
D4	1.0	Project Management Plan – BP2
D5	6.2	Concept evaluation (report)

Milestones

#	Task	Milestone Title / Description	Original Completion Date	Revised Completion Date	Actual Completion Date
M1	1	Project Management Plan	2/19/18	N/A	4/30/18 (V1.1) (On-Going)
M2	1	Kickoff Meeting	4/19/18	N/A	7/19/18
M3	2	MAP module design finalized	9/30/18	N/A	11/20/18* (Redesign Q1 2019)
M4	4	MAP prints completed	12/15/18	10/31/19	
M5	5	MAP modules installed & commissioned	2/15/19	2/15/20	
M6	5	Packing characterization completed	5/31/19	3/31/20	

Technical Objectives

- Improve upon SBIR Phase II MAP design modelling tool
  - Incorporate pressure drop, heat and mass transfer, and fluid dynamics
  - Incorporate flexibility in design through a Parametric model
  - Scale-up from 3” diameter to ~12” diameter column
- Print MAP design modules & characterize
  - 3D print prototypes
    - Engineering Plastic for mechanical fitting and to check for errors
    - Metal for packing characterization
  - Baseline characterization rig with commercially available packing
  - Modify packing characterization rig to accept MAP prototypes
  - Characterize ION MAP
- Evaluate economic benefits with ProTreat® simulation model

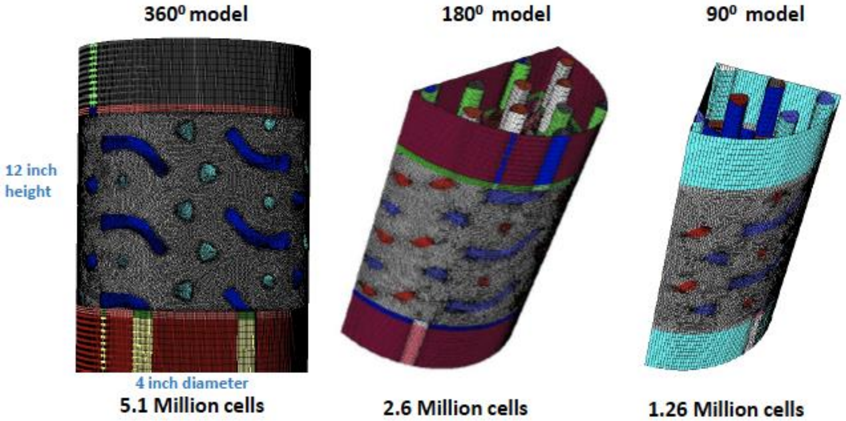
Results

CFD Model including Reactions and Heat Transfer

- Improved MAP design in collaboration with ANSYS
- Improved reaction and mass transfer equations and code
    - Successful improvement of heat transfer equations and code
    - Scaled model to use more computational power to handle increased complexity

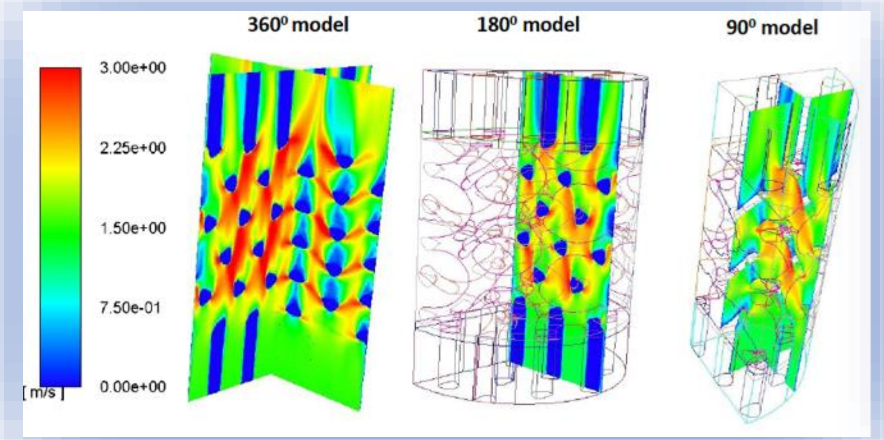
Truncated Model Approach to Overcome Complexity

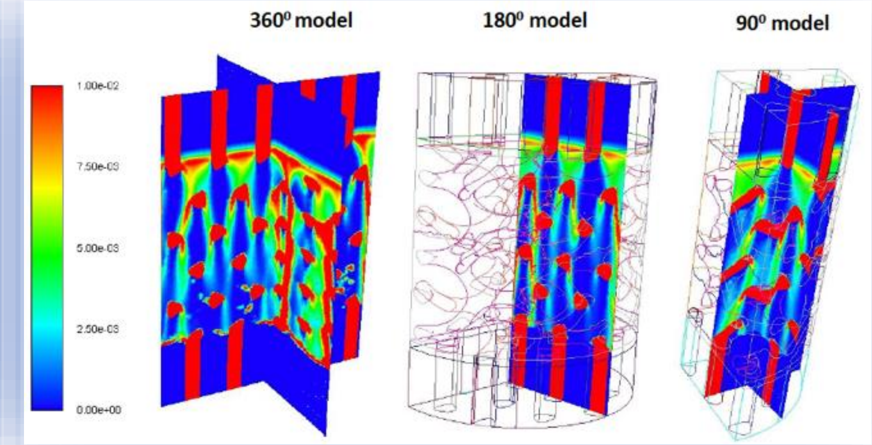
- Phase II’s 3”x12” module consisted of 5.1 million cells, which took 5 days to run
- Phase III is 10.5”x12” modules consist of 35 million cells taking 35 days for one run
- Truncated model approach researched to reduce printing times



Truncated Model Approach

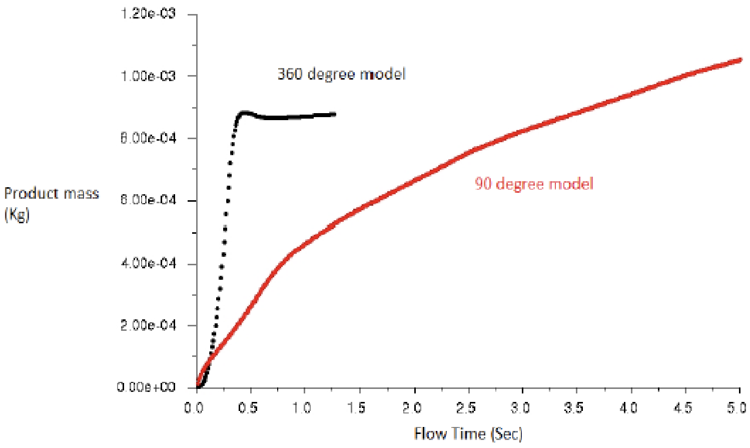
Gas Velocity and Volume Fraction

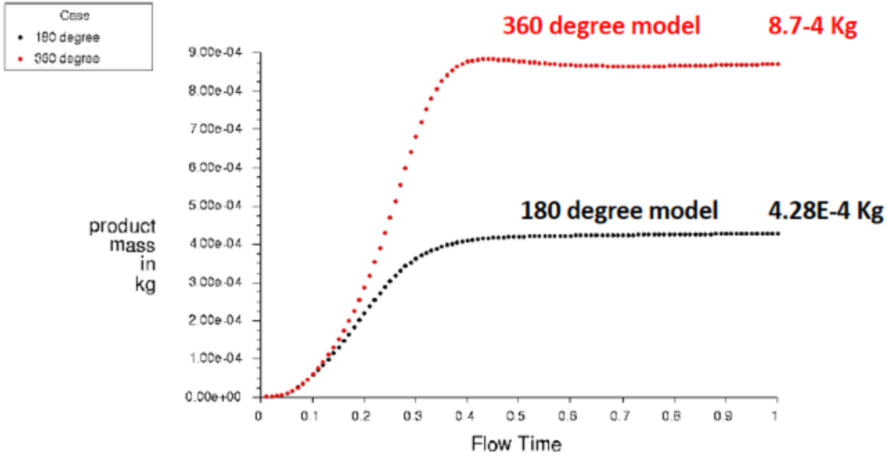




Truncated Model Approach

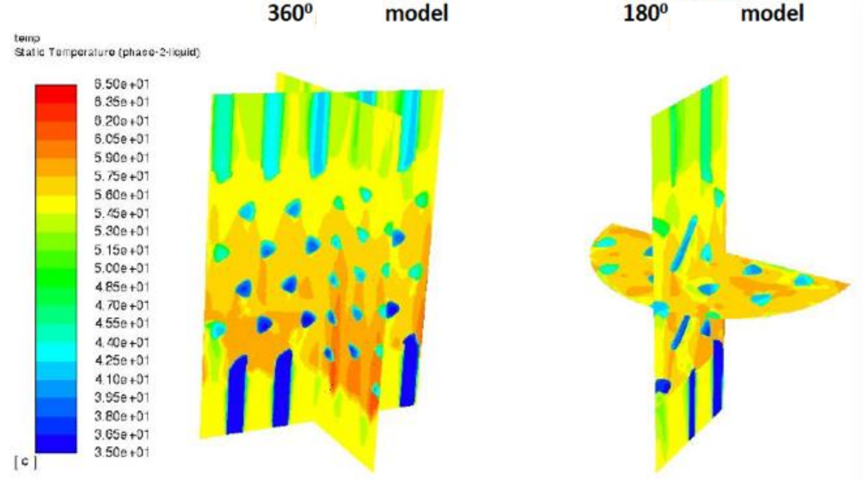
Product Mass

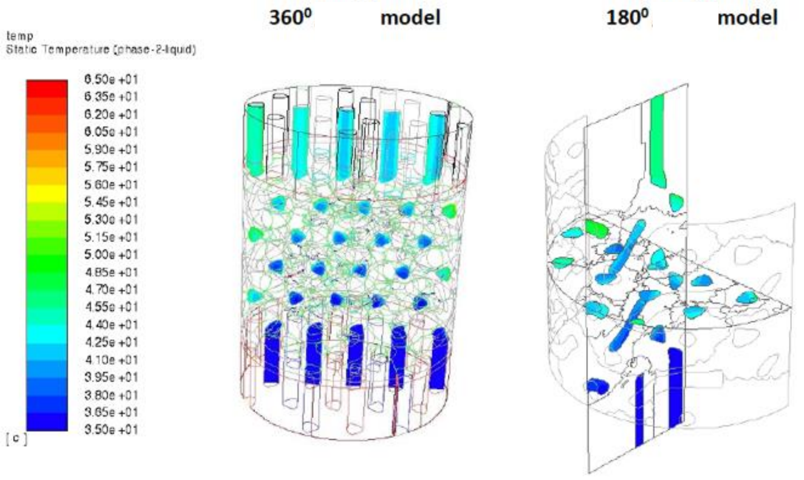




Truncated Model Approach

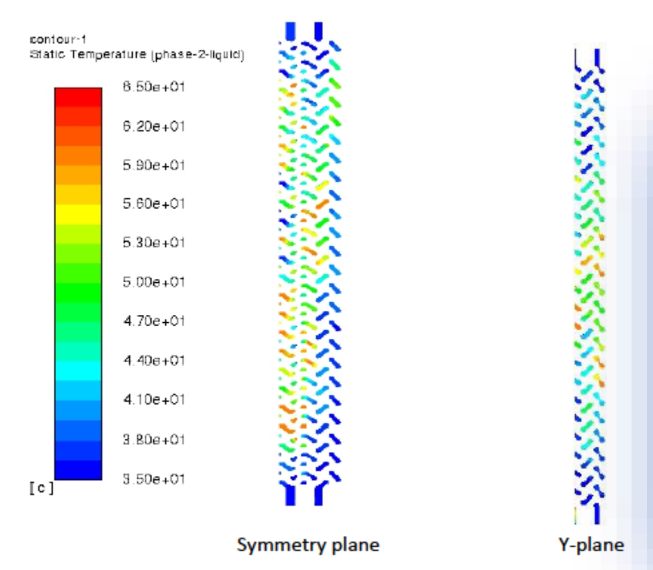
Temperature (solvent) and Cooling water

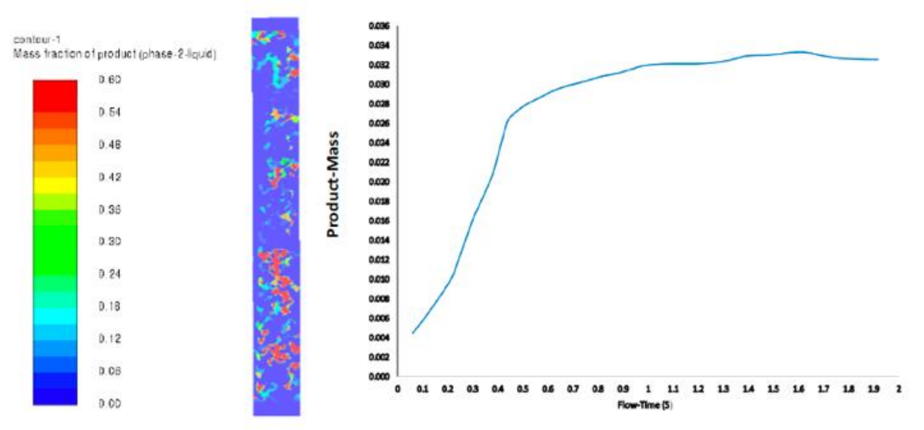




Column Sized Control - 10' High

Temperature and Product Mass Fraction





Results

3D Prints in Plastic and Metal

Next Steps

- Print remaining metal modules

- Modify and validate process models with packing characterization rig
  - Pressure drop over the height of the packing as a function of gas and liquid loads and viscosity
  - Packed bed liquid hold-up will be mapped over a broad range of column gas and liquid loads
  - Determination of effective surface area of the packings as a function of gas and liquid load will be performed by reactive experiments with CO_2 and sodium hydroxide solutions in the column
  - These tests are performed with water, sodium hydroxide and air/CO_2

Conclusions

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- Challenging CFD modelling has resulted in:
  - an advanced 3D design model by ANSYS incorporating mass transfer, reaction, heat transfer and pressure drop calculations for CO_2 capture
  - an accelerated design process
  - several designs that optimize mass transfer, heat transfer and pressure drop
- Full-size 3D prototypes have been printed in engineering plastics
- 3D metal prints are being fabricated
- Characterization facility has been designed based on ION's in-house capture pilot
- Great collaboration between project team and stakeholders

Acknowledgement and Disclaimer

Acknowledgement

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