Advancing Post-Combustion CO_2 Capture through Increased Mass Transfer and Lower Degradation

Project Number: DE-FE0031661

Performing Organization: University of Kentucky

Principal Investigator: Jesse Thompson

National Energy Technology Laboratory
2022 Carbon Management Project Review Meeting
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Project Overview

- Funded as part of the Novel and Enabling CO_2 Capture Technologies
- Project consists of three primary area: (1) modifying solvent physical properties to increase solvent wetting; (2) development of novel 3-D printed polymeric absorber packing; (3) developing an effective process to decompose nitrosamines from waterwash systems

- **Project Period:** 10/1/2018 - 9/30/2022 (3+1 years)
- **Funding**: Federal - $2.9M; CS - $725K; Total - $3.6M

University of Kentucky®

Lawrence Livermore National Laboratory

Project Objectives

Developing process enhancements/technologies that can be broadly applied to amine-based post-combustion CO_2 capture systems:

1. Hydrophobic/hydrophilic patterned packing to increase solvent turbulence and CO_2 mass transfer

2. Correlation of solvent physical properties, specifically those related to increasing CO_2 mass transfer, with wettability on absorber packing surfaces

3. Nitrosamine decomposition using electrochemical treatment within the waterwash

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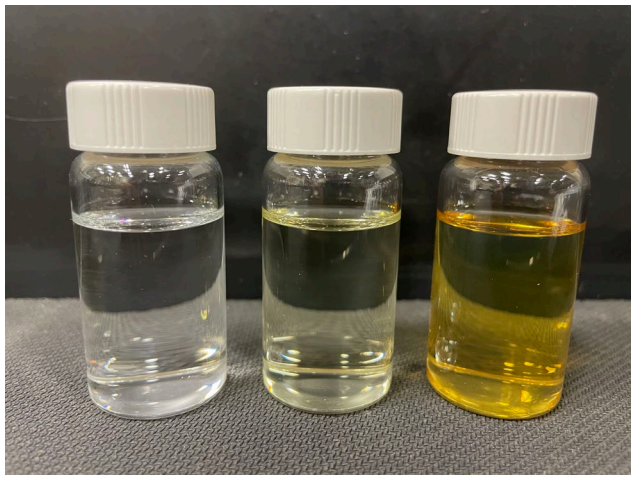
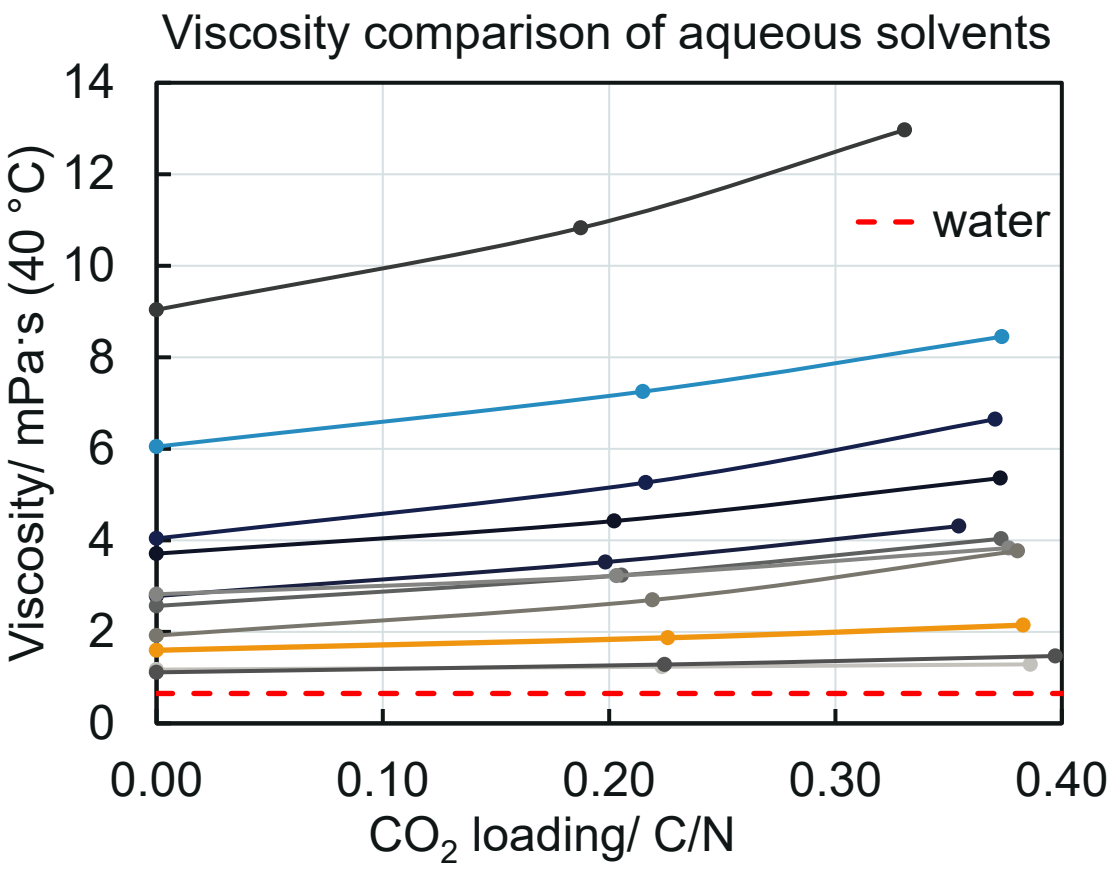
Solvent-based CO_2 Capture



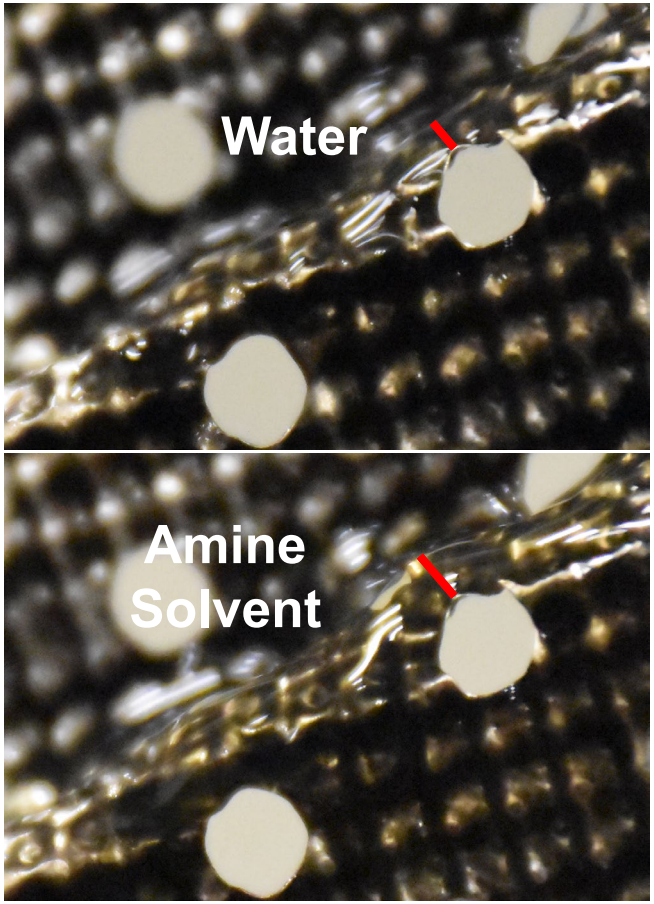
Influencing factors

- Molecular structure
- Concentration
- CO_2 Loading
- Temperature
- Impurities

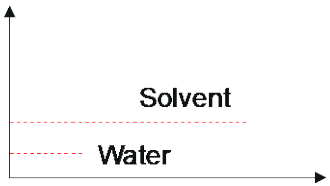


How to overcome mass transfer resistance with more viscous solvents?

Solvent-based CO_2 Capture



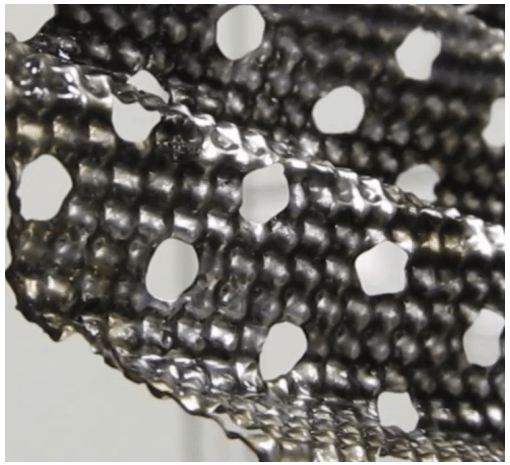
Film thickness

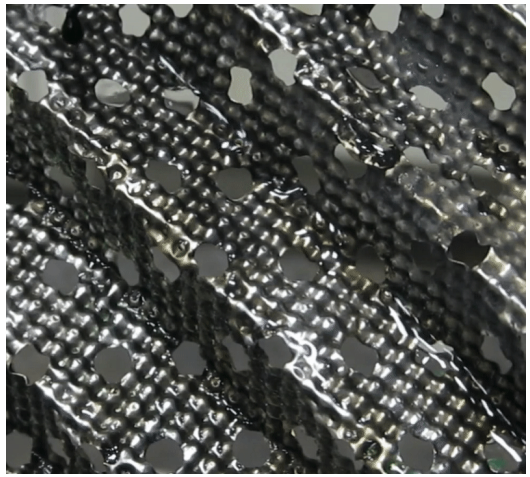


Liquid turbulence

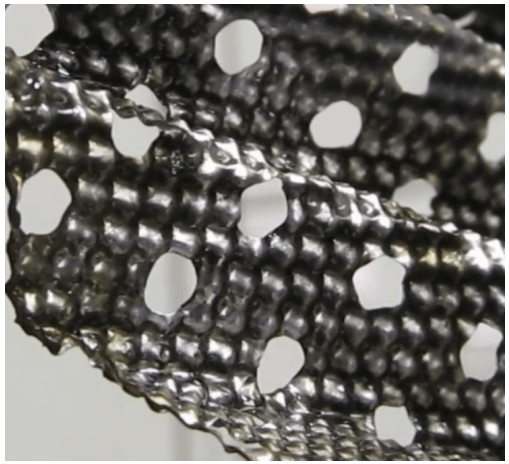
$$Re = \frac{\rho u L}{\mu\ (viscosity)}$$

Water

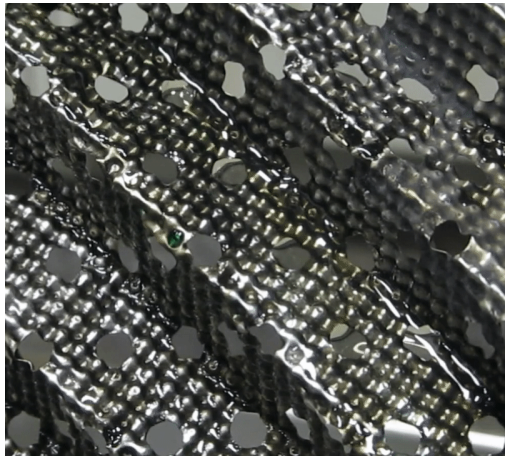




Amine Solvent

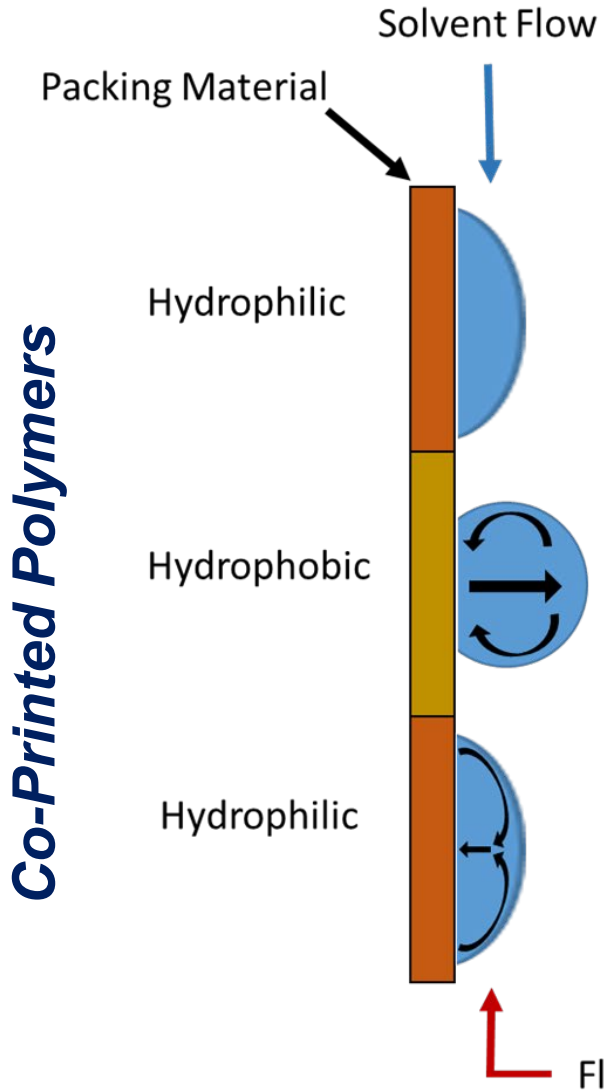


× 0.3 of original speed



× 0.1 of original speed

Dynamic Polarity Packing



Dynamic Packing with 3D Printing

Hydrophilic-hydrophilic interaction
Larger contact angle
Greater surface contact

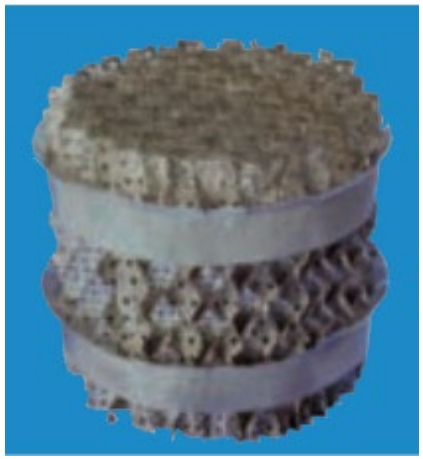
Hydrophilic-hydrophobic interaction
Smaller contact angle
Internal turbulence from solvent drawing up

Hydrophilic-hydrophilic
Packing re-wetting
More internal turbulence and mixing

Contact angle on Packing Surface

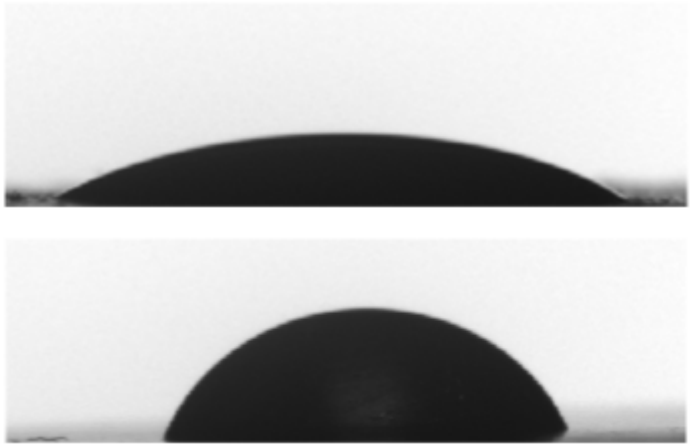
Dynamic Polarity Packing

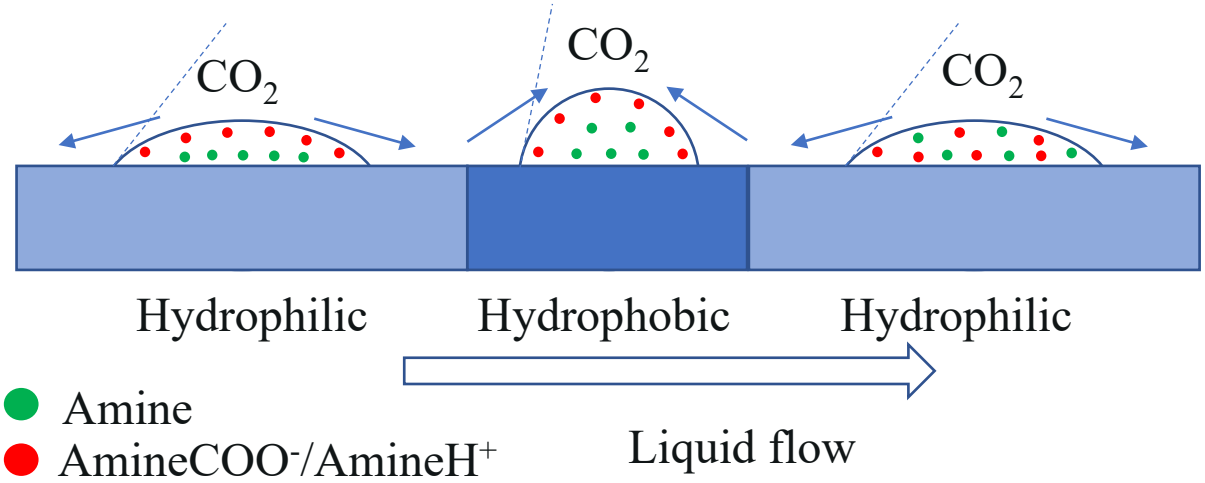
Steel



Plastic

Droplet on polymer surfaces with different polarity





Co-printed materials on packing surface

3D Printing

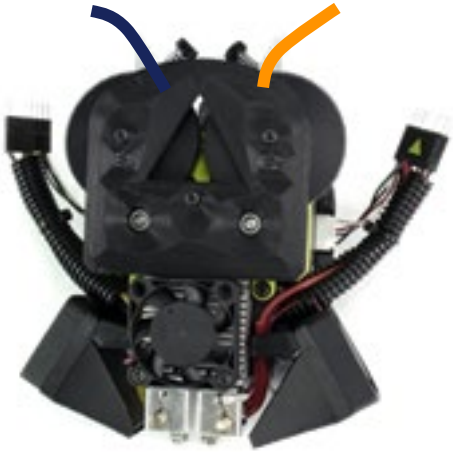
High Impact Polystyrene (HIPS)

Acrylonitrile butadiene styrene (ABS)

Nylon

Polylactic Acid (PLA)

Dual-head printer



Co-Printed Polymers

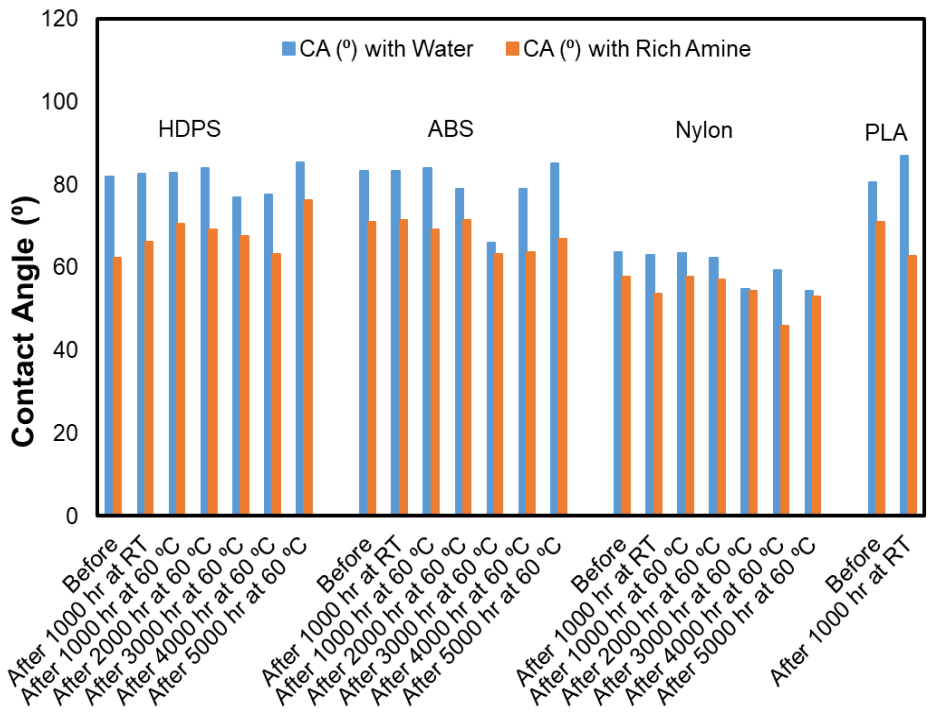
Polymer stability with amine solvents

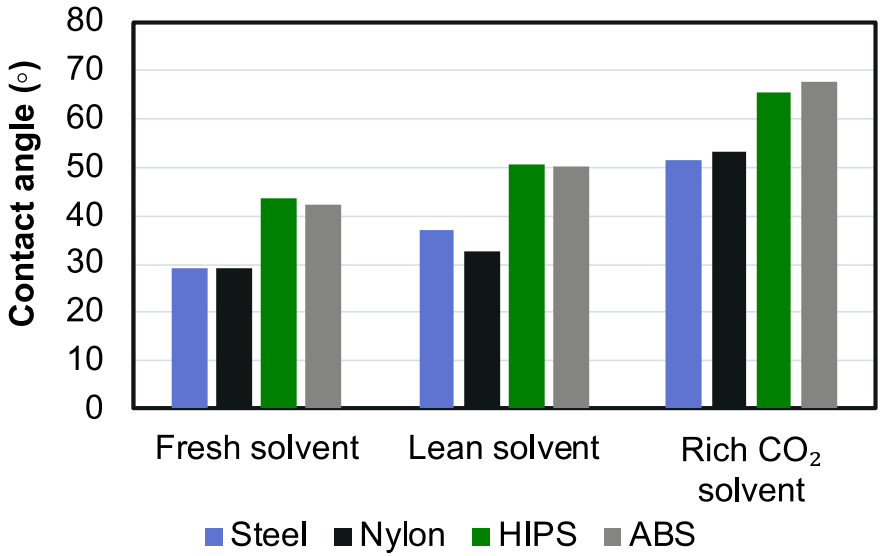
HIPS

ABS

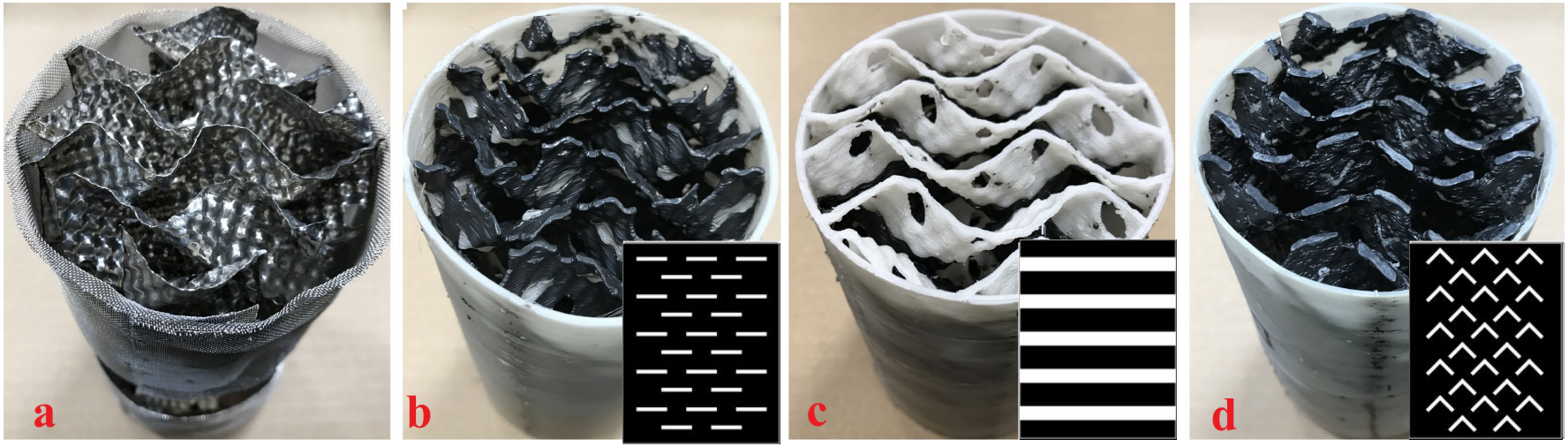
Nylon

PLA

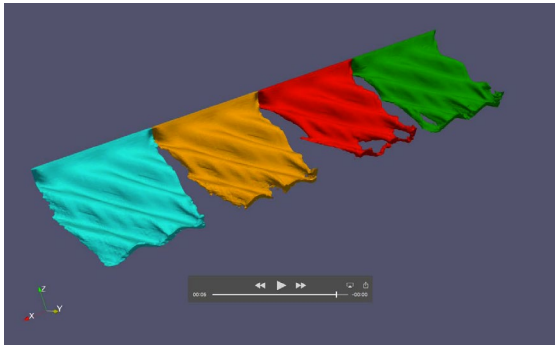


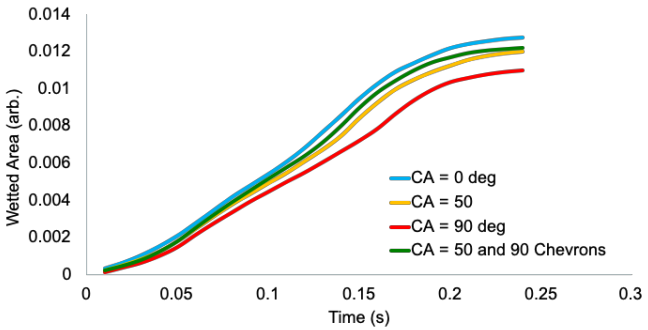


Bench Testing – Packing Design



a: Mellapak 250Y steel packing; b: DP-1 packing; c: DP-2 packing; d: DP-3 packing.





CFD modeling using the OpenFoam software

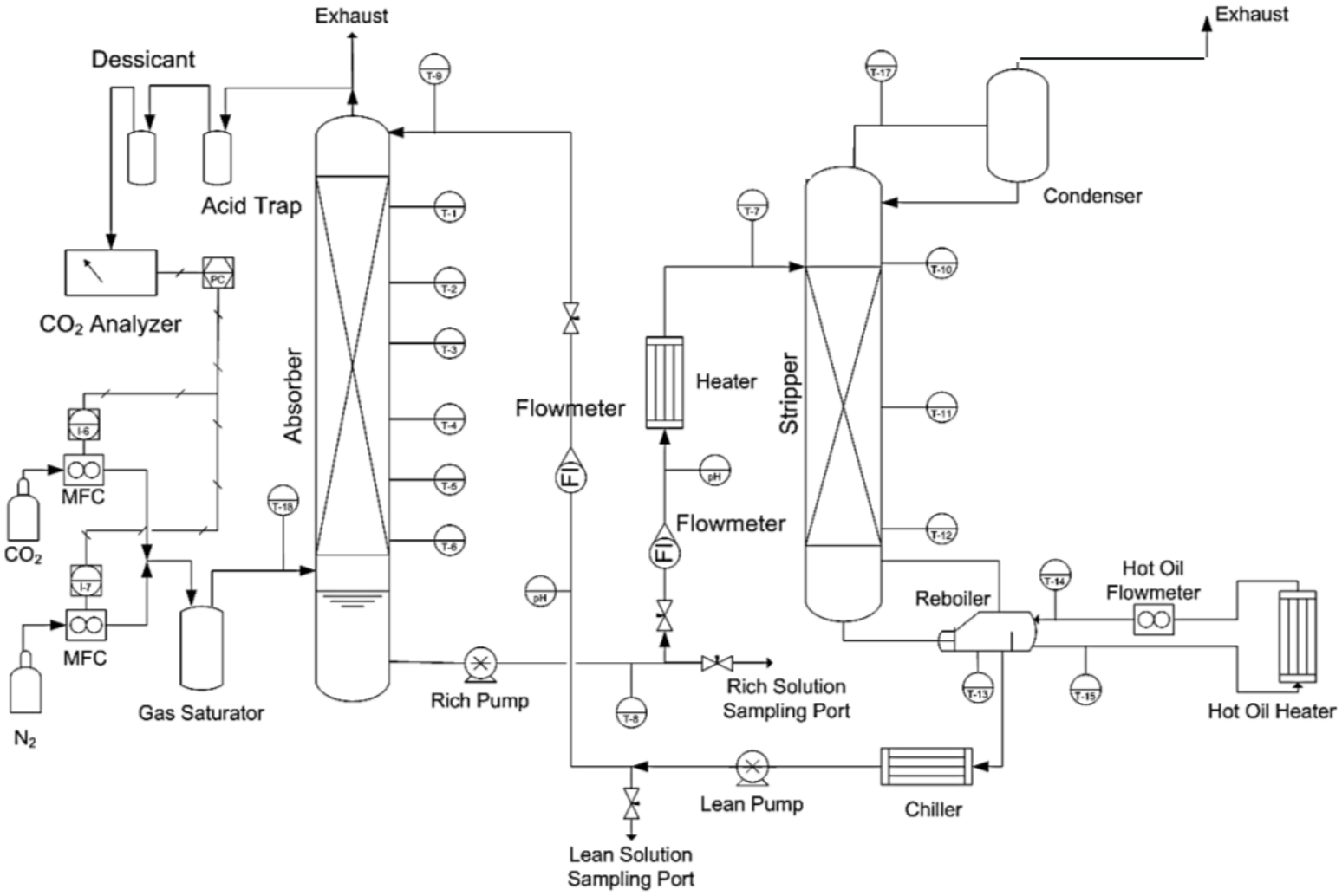
Nylon: black, ~hydrophilic

HIPS: white, ~hydrophobic

Dimensions: 3” diameter with same area and geometry as Mellapak 250Y

Bench Testing – Packing Evaluation

UK 3” Integrated Bench CO_2 Capture System w/ Simulated FG



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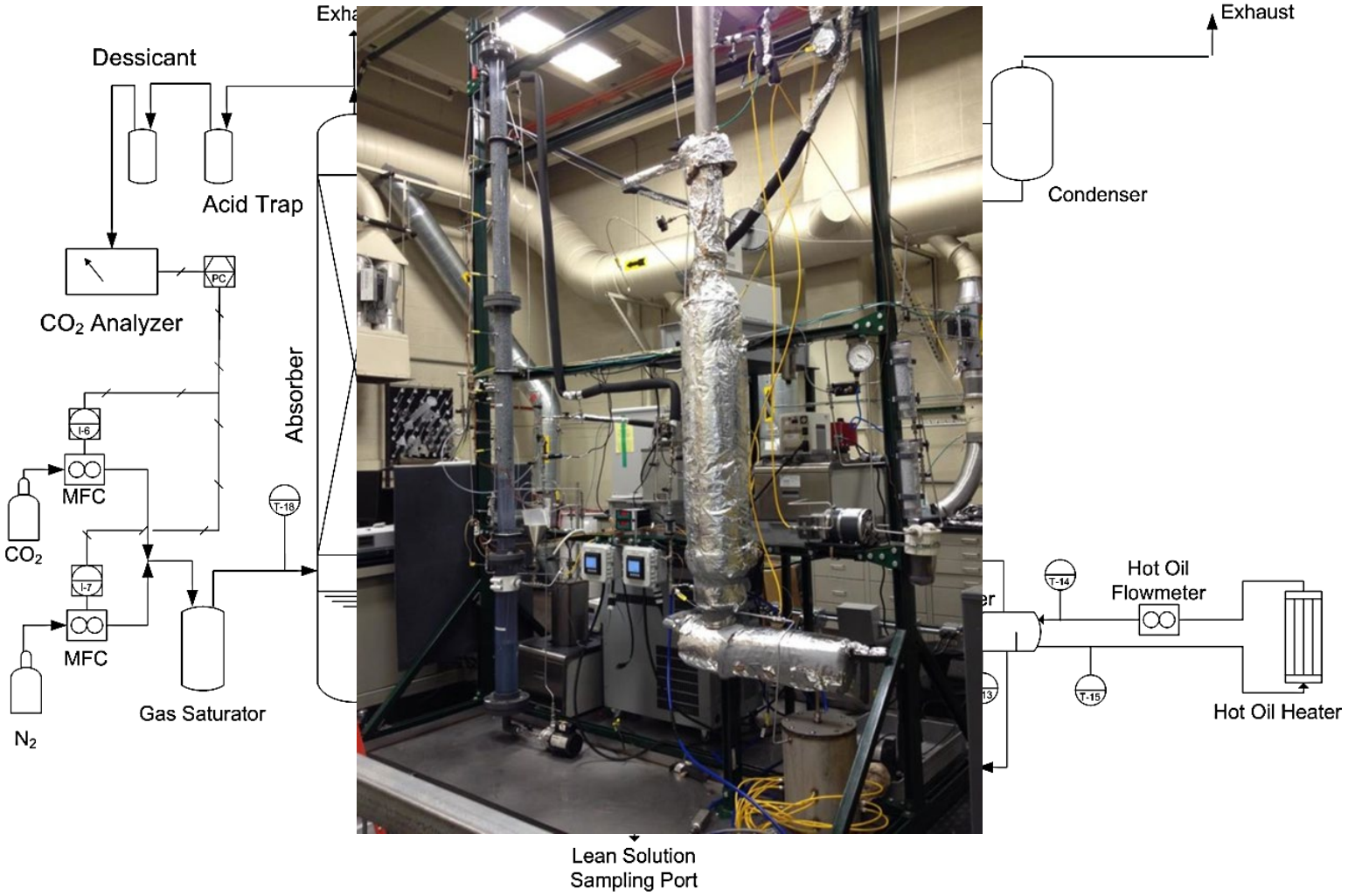
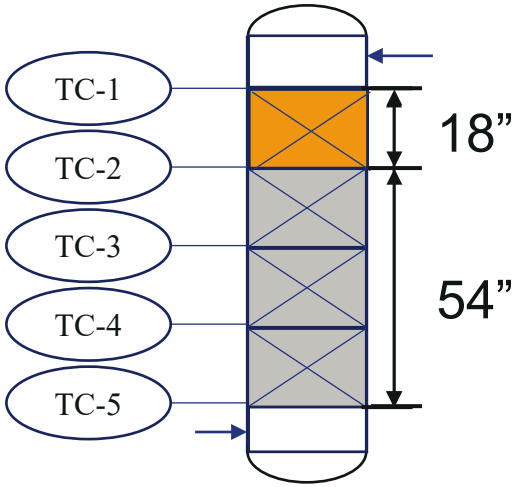
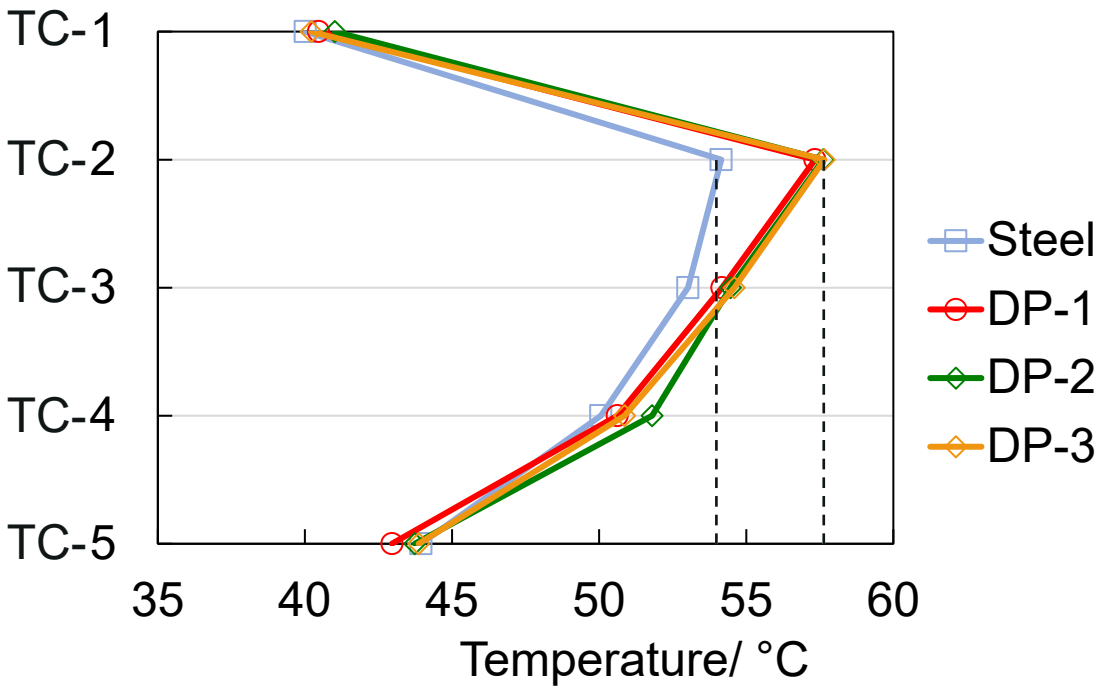


Bench Testing – Packing Evaluation

Packing installation





Baseline

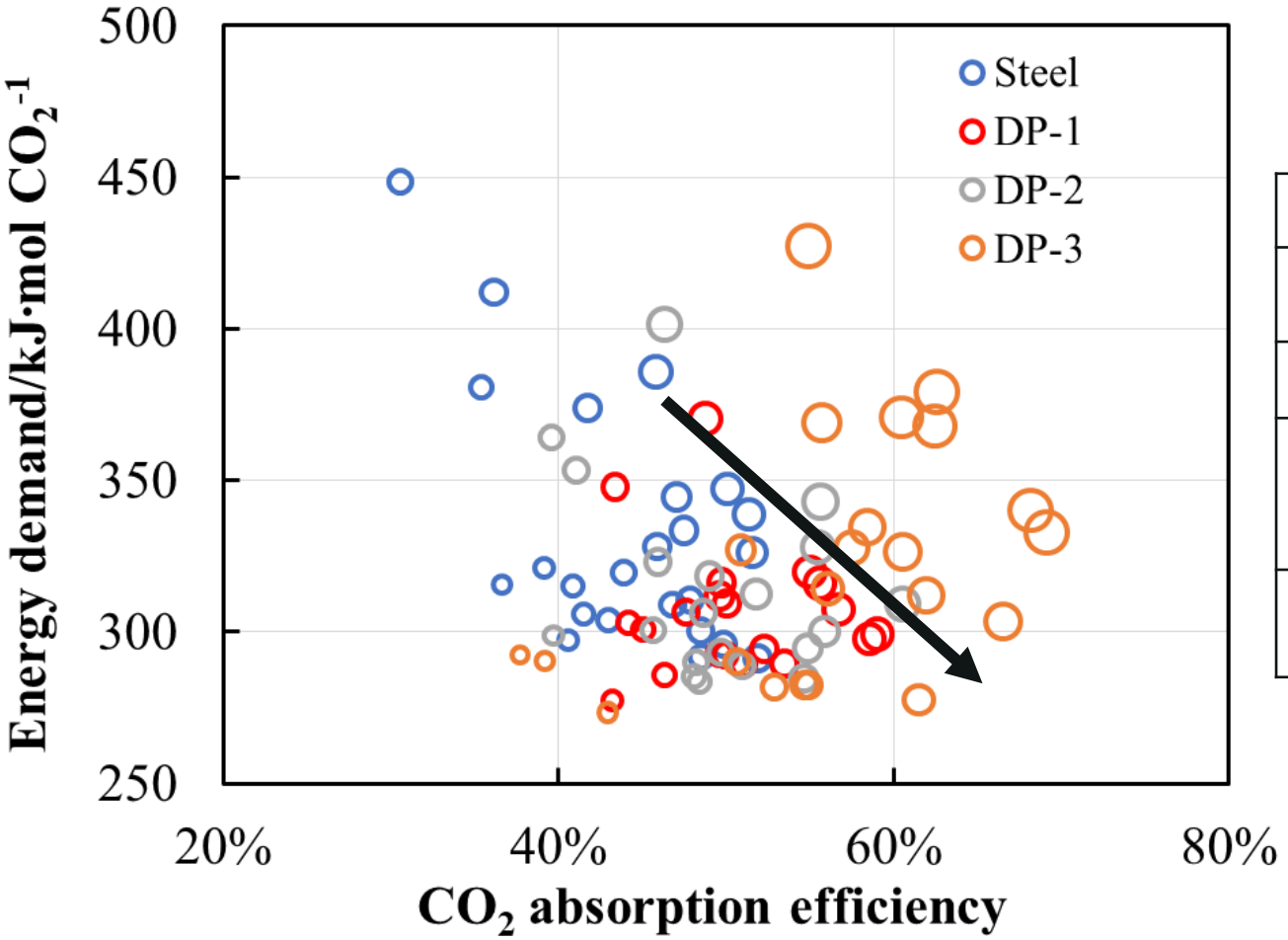
- 250Y Steel packing - 72”

Alternative

- DP packing - 18”
- 250Y Steel packing - 54”

Conditions	
L/G ratio (kg/kg)	2.6
Lean loading (C/N)	~0.23
Lean return temperature (˚C)	40

Bench Testing - Parametric



Inlet CO_2	14%
L/G (Kg/Kg)	1.7, 2.6, 3.5
Stripper Pressure (kPa)	110-180
Stripper Temp (ºC)	105-120

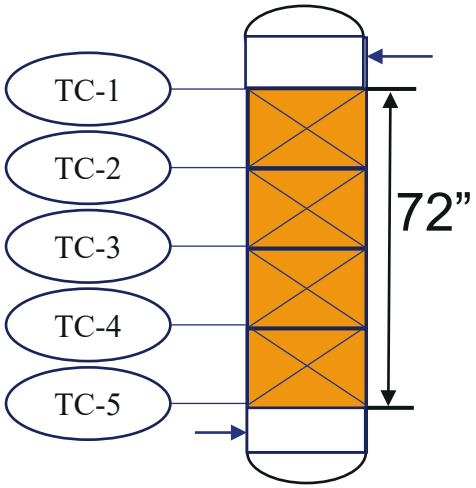
DP packing with enhanced solvent achieved an average increase in CO_2 absorption efficiency of 22.7% and a 20.0% decrease in energy penalty compared to reference steel packing during parametric testing

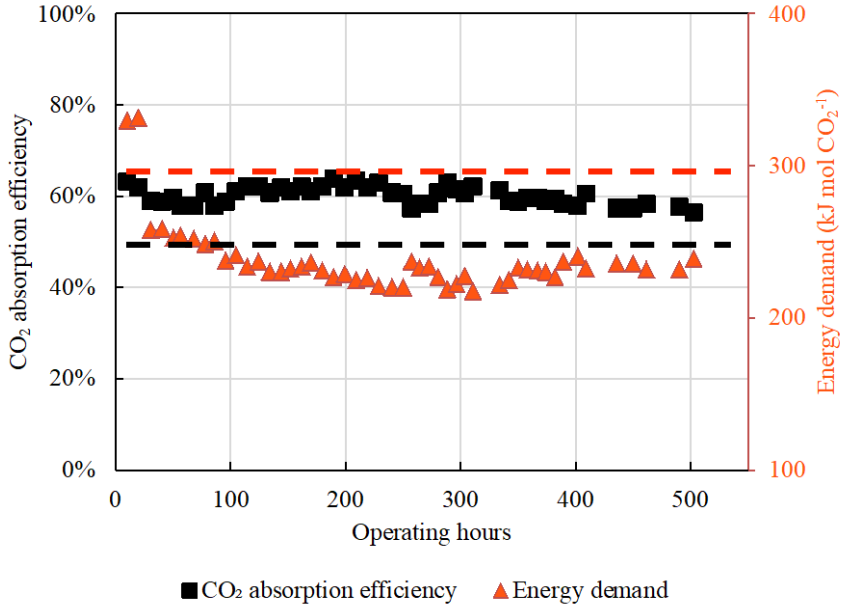
Bench Testing : Long-term

BP2: Fabrication of 3” diameter Dynamic Packing and installation into our small-bench CCS, followed by 500 hrs. of long-term integrated solvent/packing testing

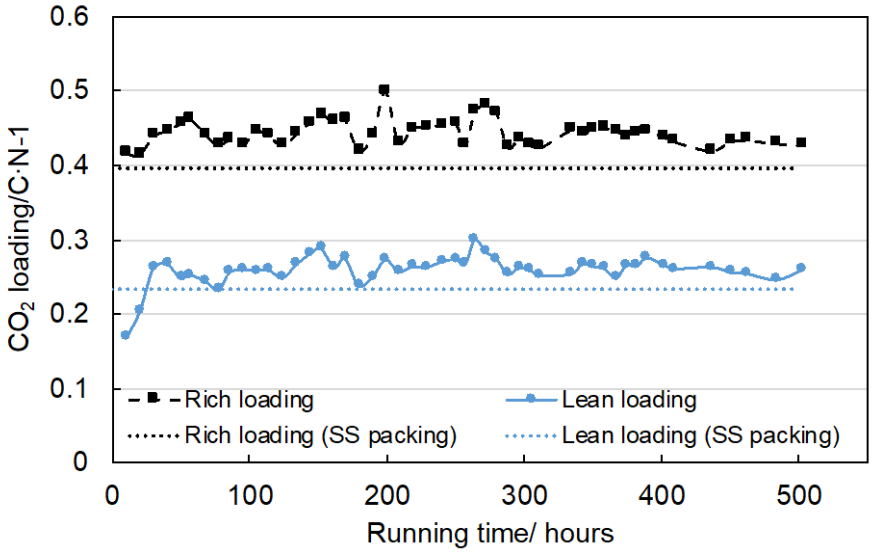
Primary goals for long-term testing are: (1) evaluate packing stability including contact angle and physical changes, and (2) assess the impact of solvent degradation on the packing and the impact of the packing on solvent degradation

Bench Testing : Long-term



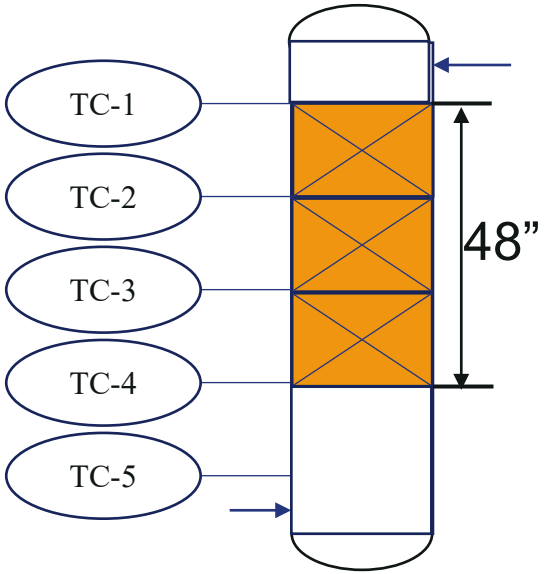


	CO_2 absorption efficiency	Energy demand
Improvement compared to reference	↑ 17.4%	↓ 18.6%

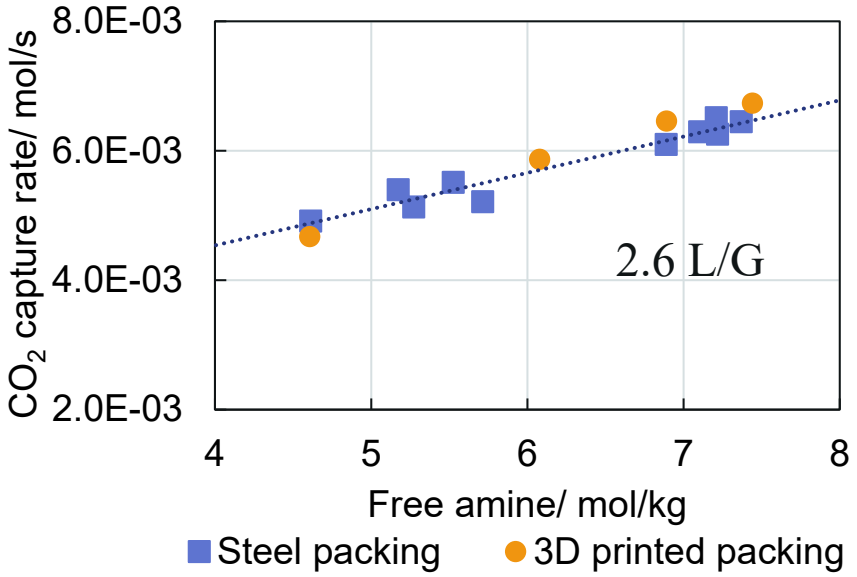


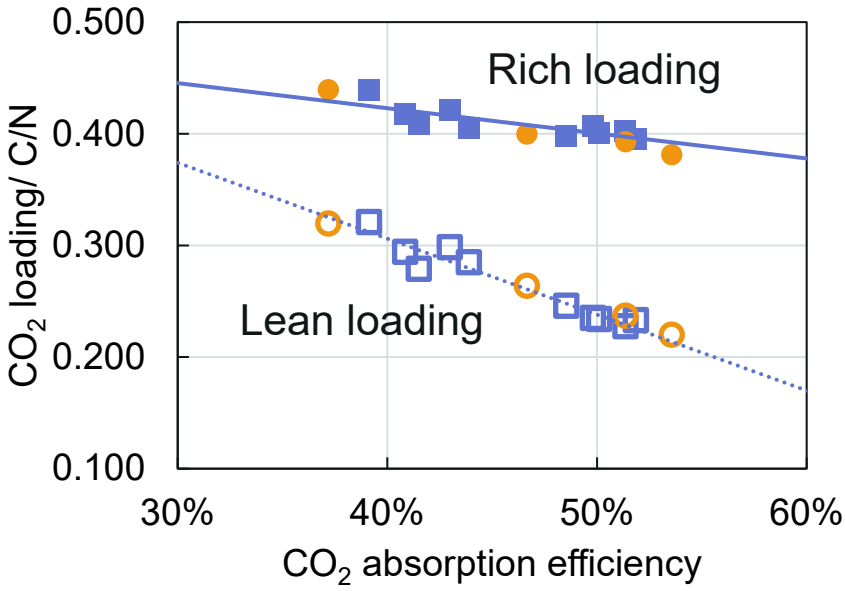
No observed changes in contact angle or physical changes of packing, and no impact on solvent degradation

Bench Testing : Shorter column



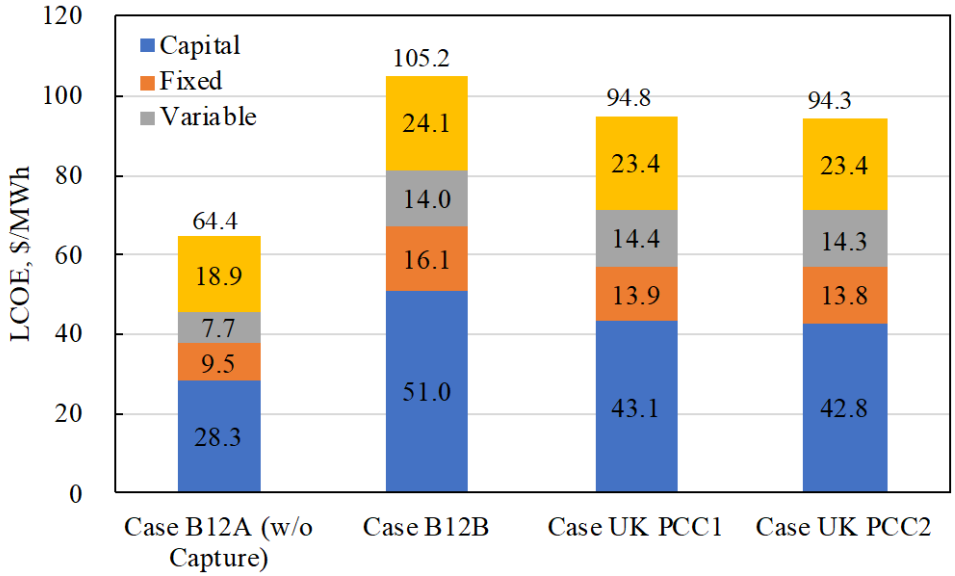
2/3 of 250Y Steel packing height

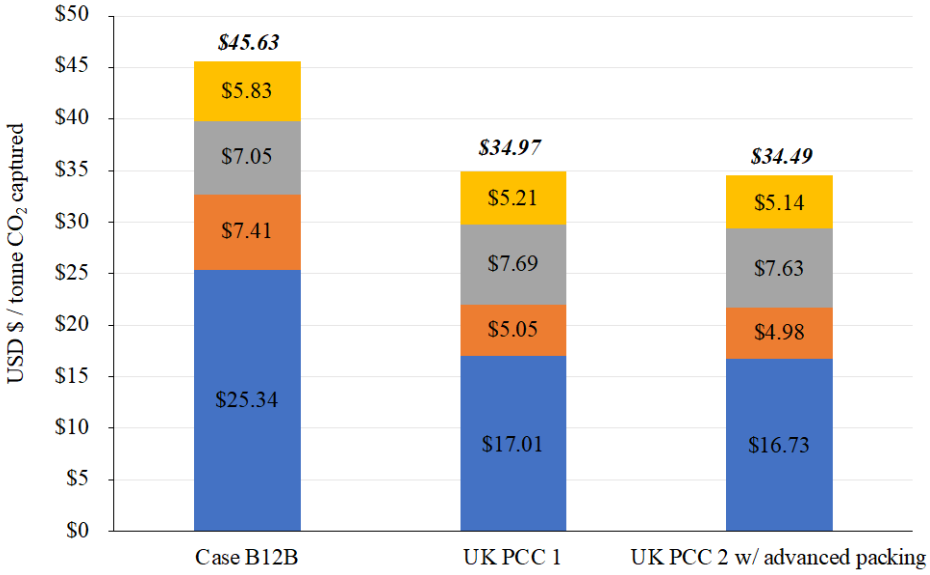




Less packing through intensified mass transfer = smaller absorber with lower capital costs

TEA - Highlights



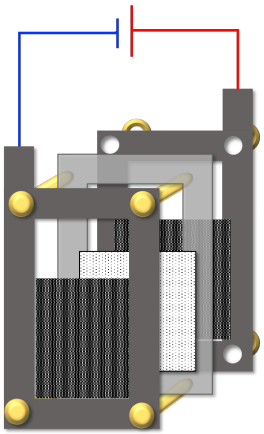


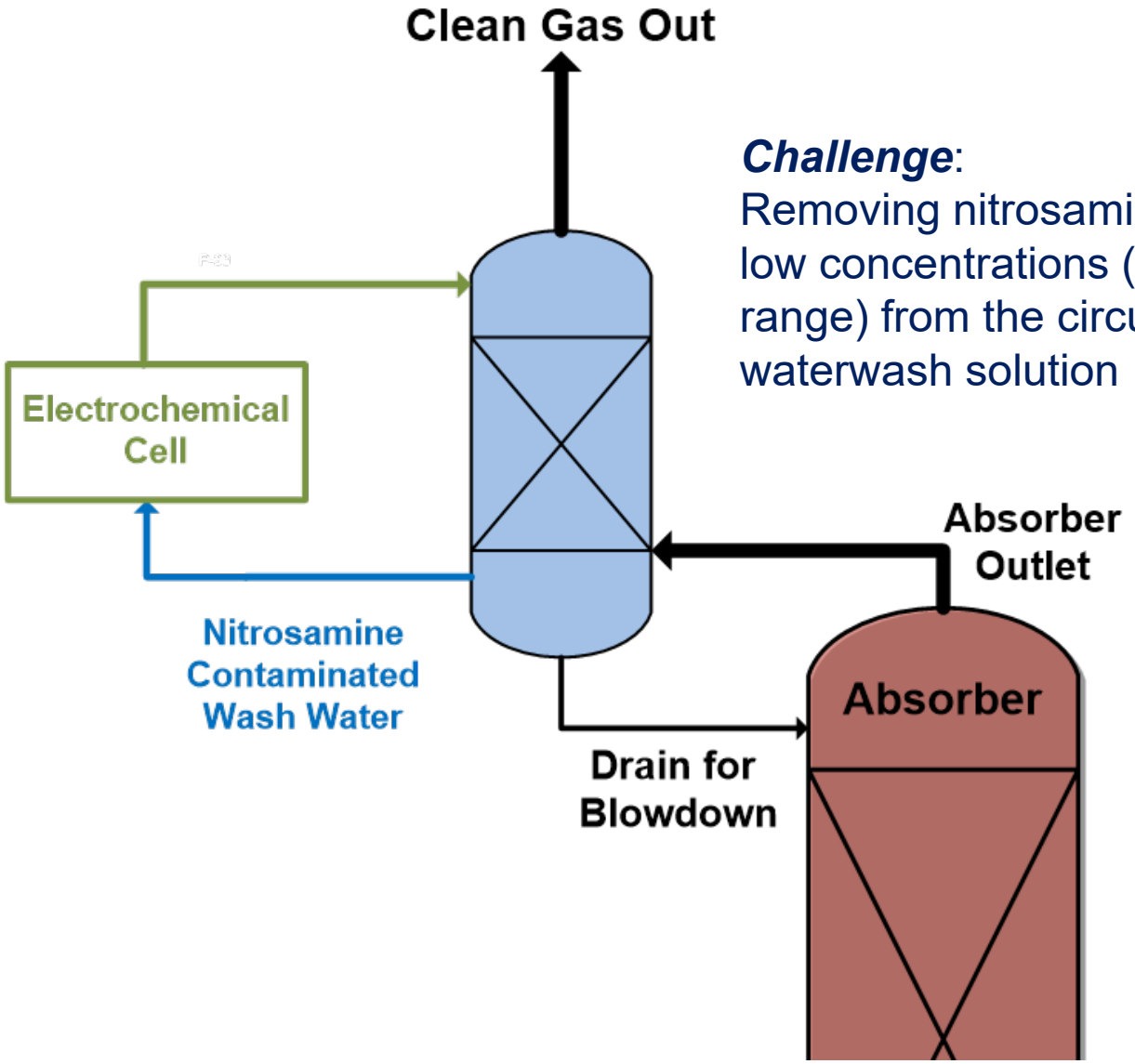
- TEA was prepared for the UK CO_2 capture process (w/ UK solvent) and advanced packing in the absorber to enhance mass transfer and decrease the absorber size (no cost saving with polymer packing vs steel was included in calculations)

- The UK process with advanced packings shows a reduction in levelized cost of electricity (~10.4%), and cost of CO_2 capture (~24.4%)

UK PCC1 case reported in DE-FE0031604

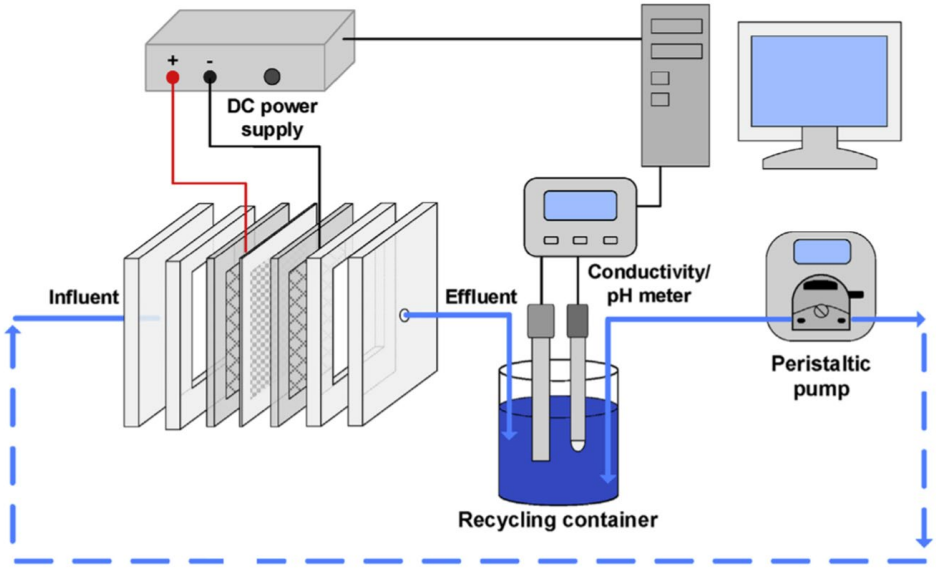
Nitrosamine Mitigation

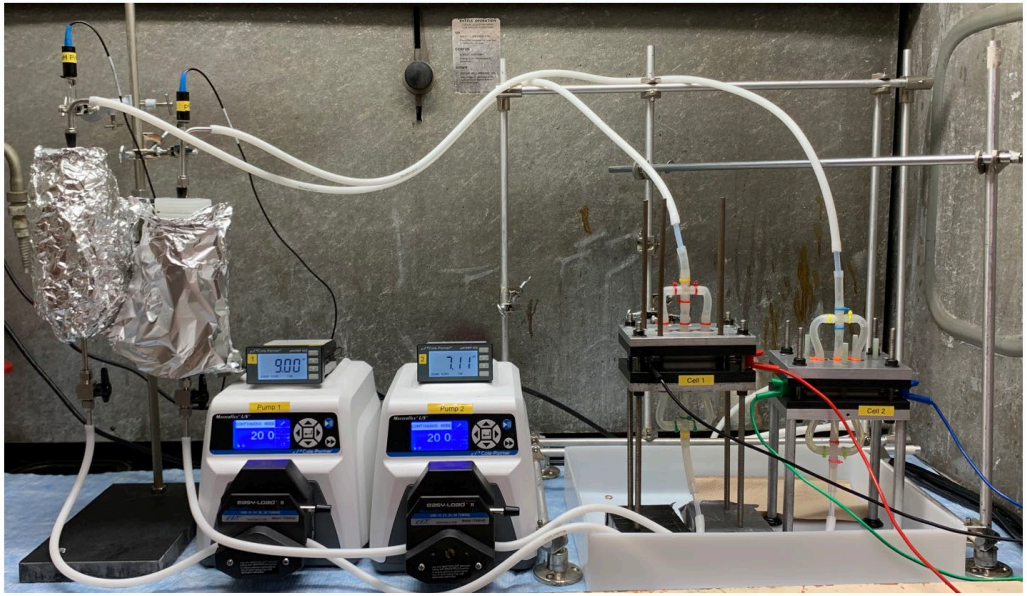




Challenge:
Removing nitrosamines at very low concentrations (ppb - ppm range) from the circulating waterwash solution

Nitrosamine Mitigation





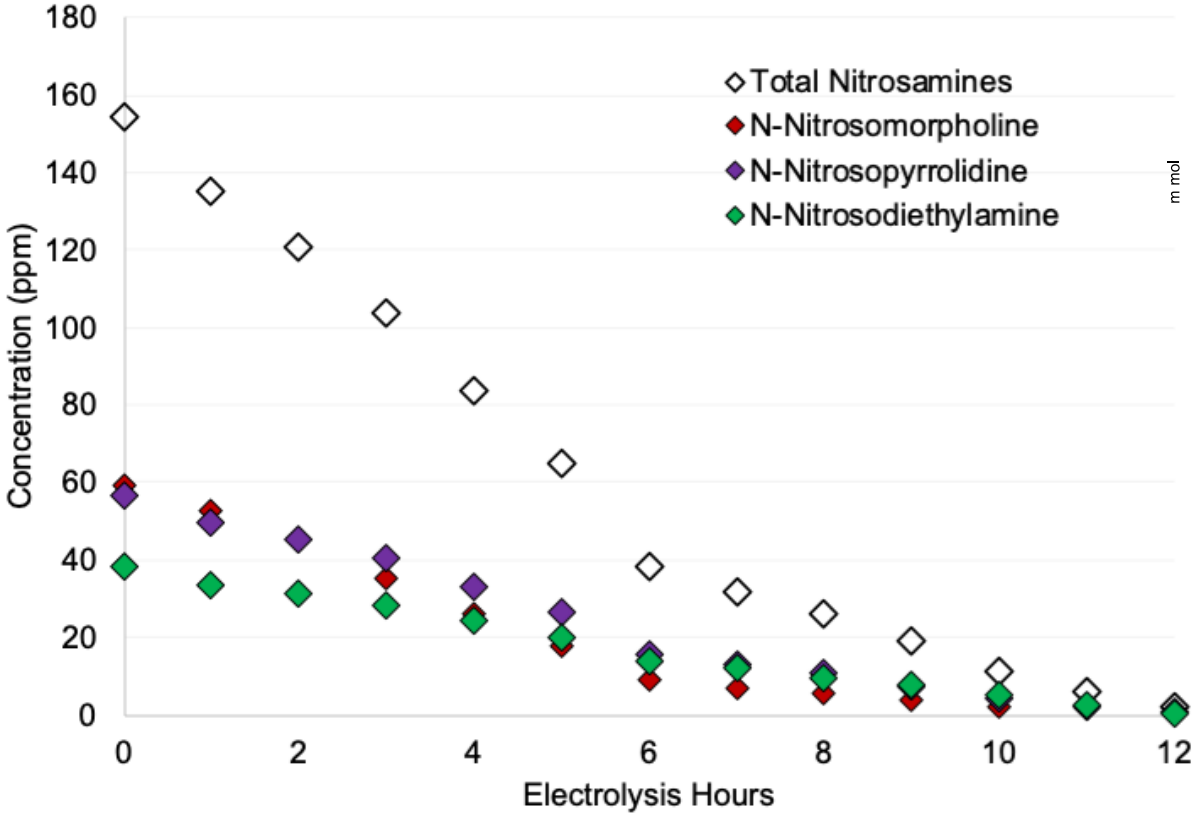
Development tasks:

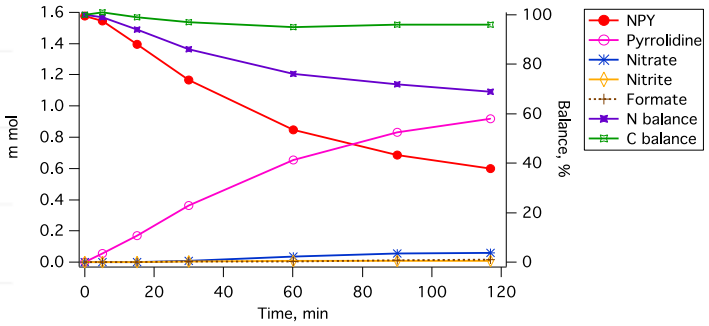
- Fabrication of flow-through electrochemical cell
- Optimized nitrosamine removal and efficiency
- Tested using authentic waterwash collected at our 0.7 MWe Small Pilot CCS

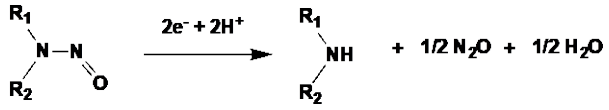
Key properties:

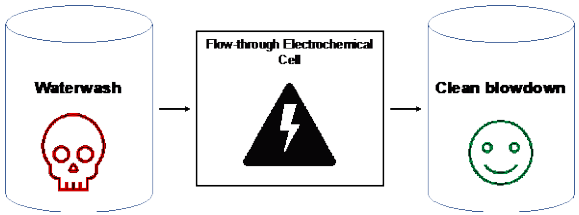
- Flow-through design for constant treatment
- Ability to *decompose* a variety of *nitrosamines* to *below detection limits*
- Does not degrade amines
- Small footprint and energy usage

Nitrosamine Mitigation





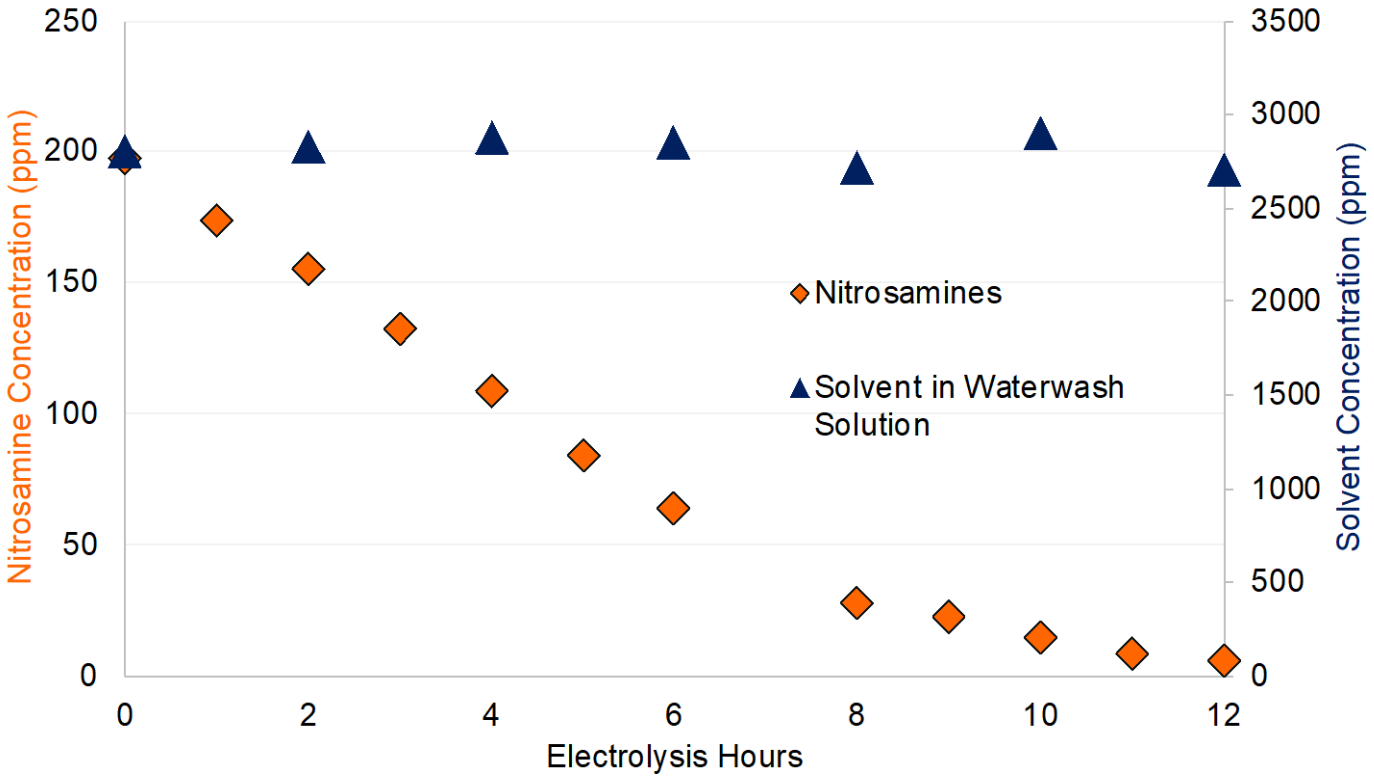




Target: > 60% removal of nitrosamines and 20% efficiency

Achievement: >99% nitrosamine removal (below LOD) at ~30% efficiency; Primary product is regeneration of the parent amine with minimal amine decomposition in waterwash

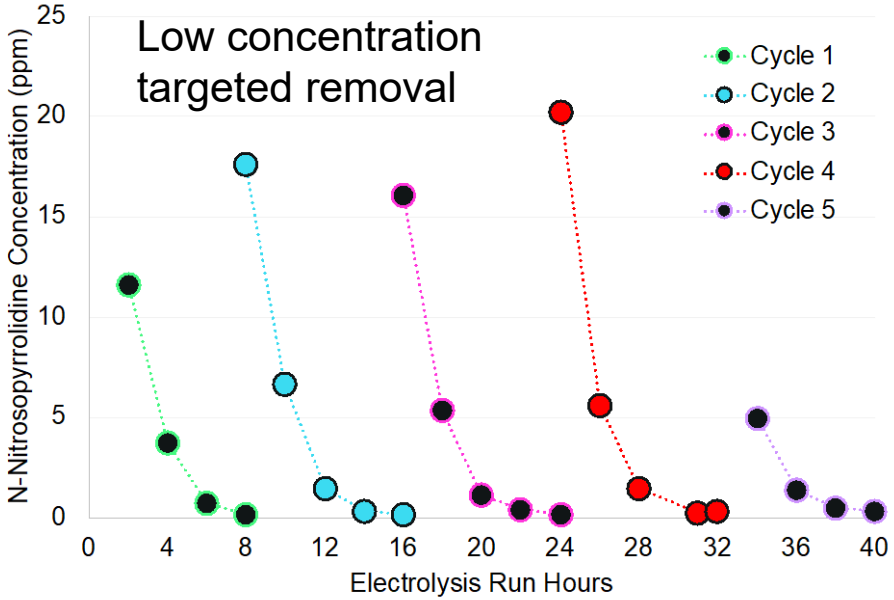
Nitrosamine Mitigation

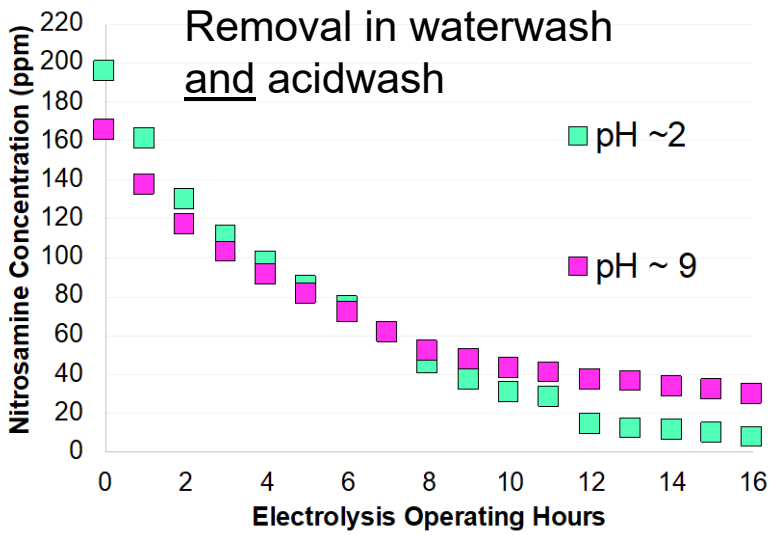


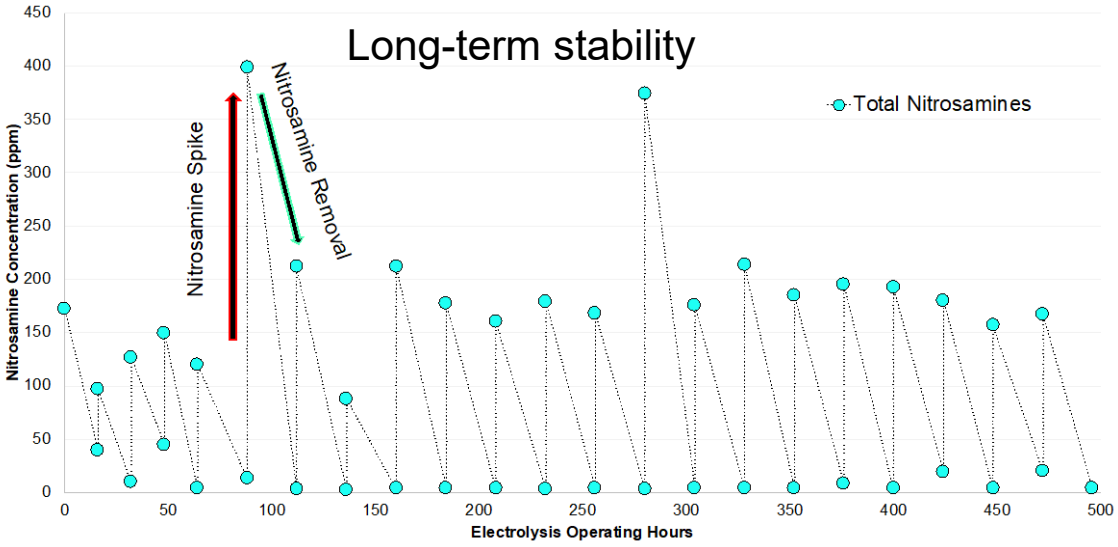
UK CAER 0.7MWe Small Pilot Carbon Capture System

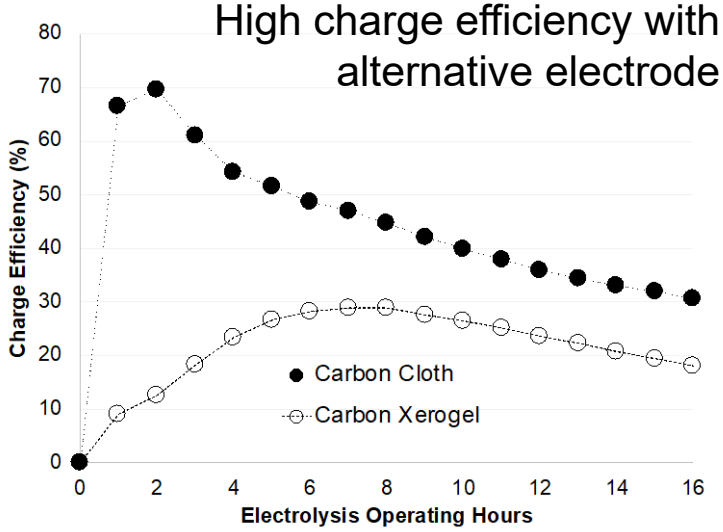
Electrochemical cell operates with no matrix effects, ~99% removal to below LOD

Nitrosamine Mitigation









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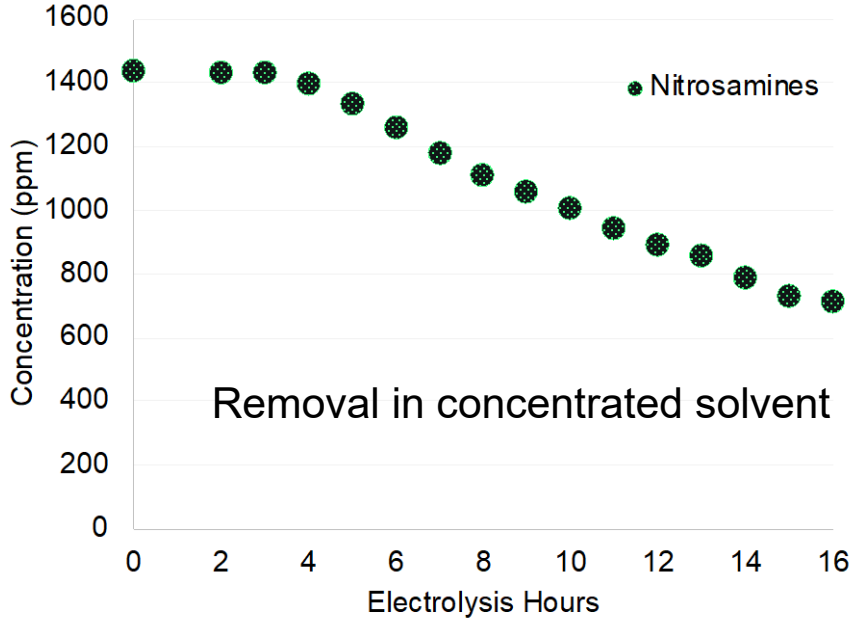
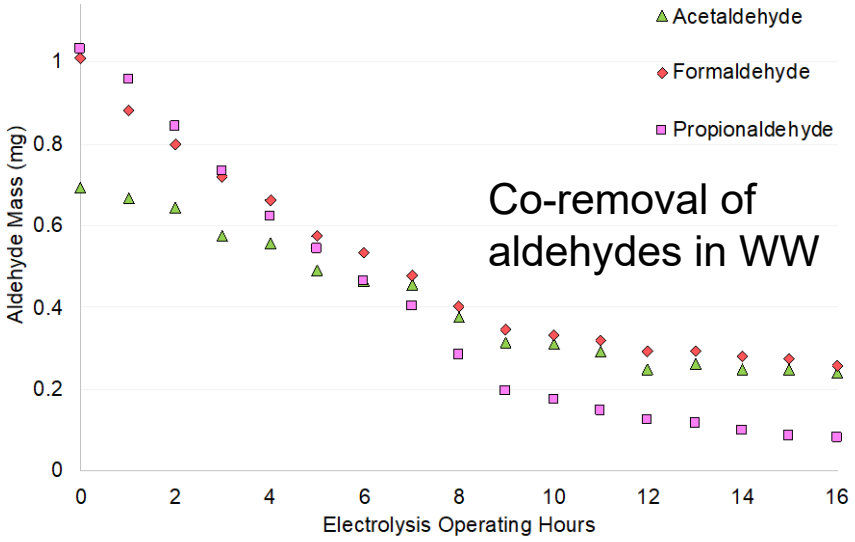




- Our electrochemical flow cell process is effective at removing nitrosamines from waterwash solutions with 90-99% efficiencies

- Degradation reaction is electrochemical reduction of the nitrosamine back to the parent amine

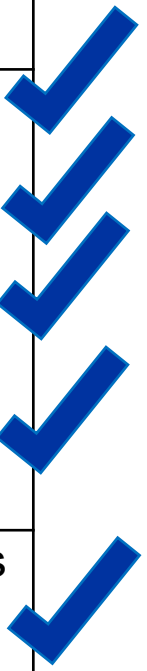
- The electrochemical process is beneficial as it does not decompose the solvent in the waterwash

- Not preferential to any one nitrosamine structure

- This electrochemical cell can be adapted to decompose nitrosamines in the solvent with further optimization

Success Criteria

Decision Point	Date	Success Criteria
Completion of BP1	3/31/2020	1. Production of a 3” sections of dynamic packing 2. Dynamic packing to achieve the target 20% mass transfer enhancement 3. A completed test matrix plan for the dynamic packing and solvent test campaign 4. Production of an electrochemical cell capable of being decomposing nitrosamines below the target value of 60% removal
Project Completion	9/30/2022	1. A stable operation with average of 20-30% less energy consumption compared to MEA reference 2. Completed high level technical and economic analysis of the proposed process concepts

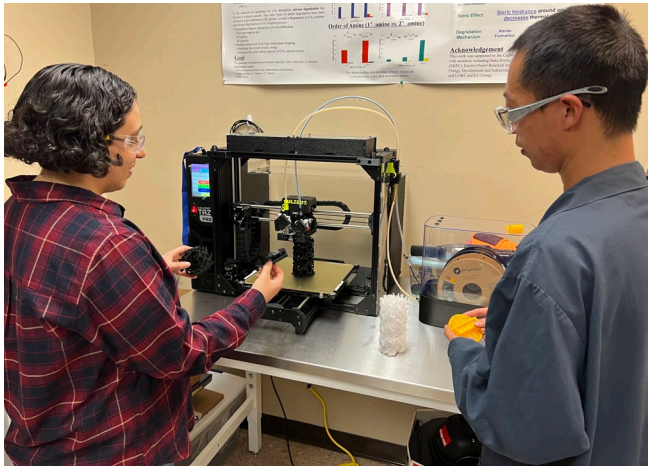


Conclusions

- Dynamic polarity packing contributes to increased cyclic capacity and decreased solvent requirement (L/G) to reduce the absorbent cost and pump work
  - Solvent can be operated at a higher CO_2 loading region with less water content to reduce regeneration energy
- Applicable to both aqueous and non-aqueous solvents
- Reduced absorber size for lower capital costs

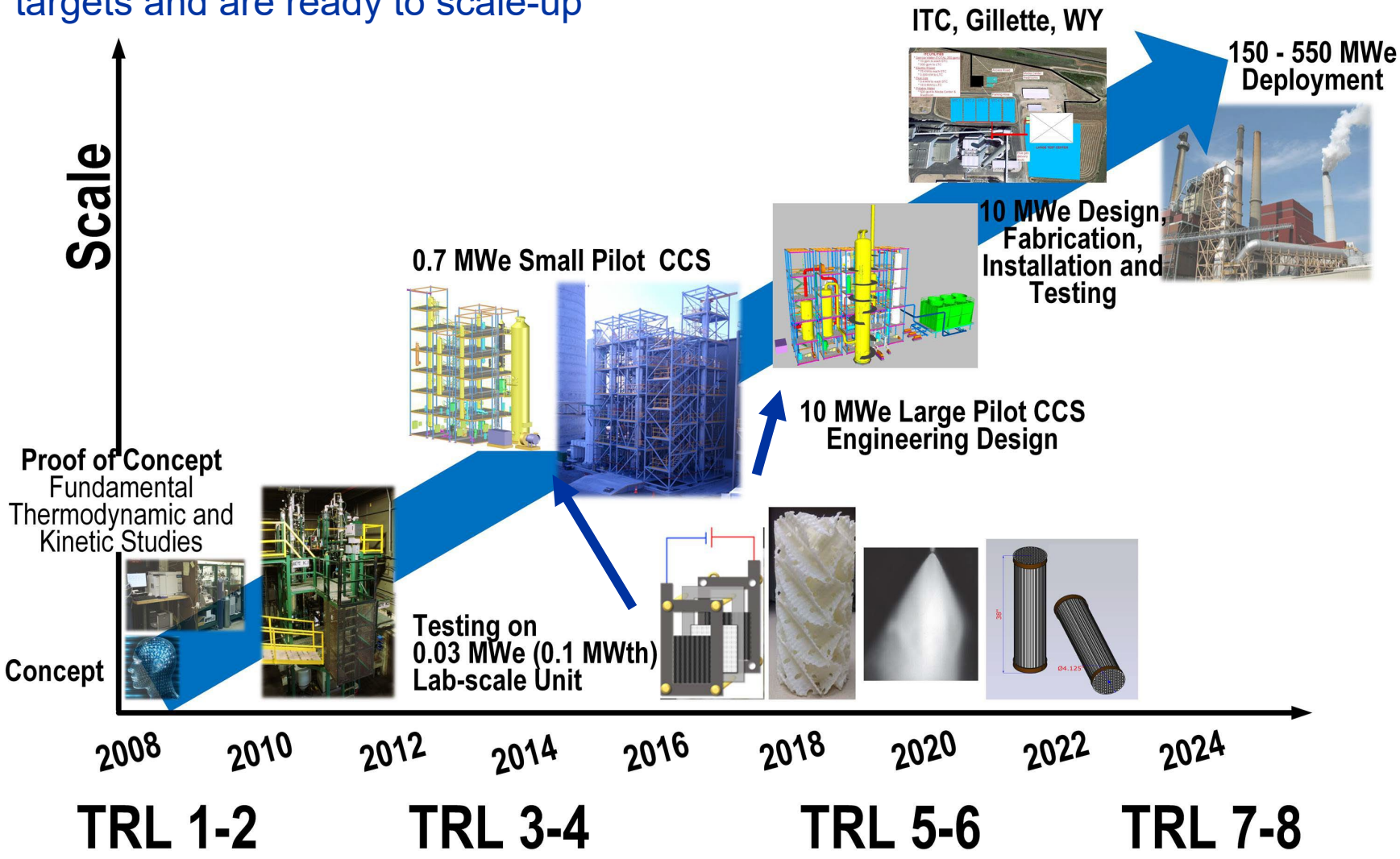
Key Knowledge Gained

- Dynamic polymer packing is a promising lower-cost alternative for CO_2 capture absorbers
- Amine solvent physical properties can be modified through the addition of additives to decrease surface tension and increase wettability on packing surfaces
- Nitrosamine decomposition can be achieved using an electrochemical treatment process.



Next Steps – Technology Development

Our technologies have met/surpassed performance targets and are ready to scale-up



Publications and Presentations

- Jorgensen, T.; Abad, K.; Sarma, M.; Guzman, M. I.; Thompson, J. G.; Liu, K. "Research on oxygen solubility in aqueous amine solvents with common additives used for CO_2 chemical absorption" *International Journal of Greenhouse Gas Control*, 2022, 116, 103646. DOI: 10.1016/j.ijggc.2022.103646
- Xiao, M.; Sarma, M.; Thompson, J.; Nguyen, D.; Ruelas, S.; Liu, K. "CO_2 absorption intensification using three-dimensional printed dynamic polarity packing in a bench-scale integrated CO_2 capture system" AIChE Journal, 2022. DOI: 10.1002/aic.17570
- Sarma, M.; Abad, K.; Nguyen, D.; Ruelas, S.; Liu, K.; Thompson, J. "Investigation of chemical stabilities and contact angle of 3D printed polymers with CO_2 capture solvents to enhance absorber performance" International Journal of Greenhouse Gas Control, 2021, 111, 103478. DOI: 10.1016/j.ijggc.2021.103478
- Oral Presentation: "High efficiency decomposition of N-nitrosamines in waterwash solutions from CO_2 capture systems" Authors: Keemia Abad Meeting: University of Texas 6th Conference of Carbon Capture and Storage (UTCCS-6), Virtual Meeting 25-27th Janurary, 2022.
- Oral Presentation: "DO Measurements in Amine Solvents" Authors: Thomas Jorgensen Meeting: University of Texas 6th Conference of Carbon Capture and Storage (UTCCS-6), Virtual Meeting 25-27th Janurary, 2022.
- Oral Presentation: "Degradation of Aqueous Amine Solvents from Small Pilot Carbon Capture System" Authors: Saloni Bhatnagar Meeting: University of Texas 6th Conference of Carbon Capture and Storage (UTCCS-6), Virtual Meeting 25-27th Janurary, 2022.
- Oral Presentation: "Mass Transfer Intensification Using 3D Printing Novel Dynamic Polarity Packing for Post Combustion Carbon Capture", Authors: Min Xiao, Moushumi Sarma, Kunlei Liu and Jesse Thompson. Meeting: AIChE 2021 Annual Meeting, November 7-11, Boston, MA.
- Oral Presentation: "Enhancing solvent CO_2 mass transfer through increased wetting bymodifying solvent surface tension using additives" Authors: Saloni Bhatnagar, Min Xiao, Moushumi Sarma, Kunlei Liu, Jesse Thompson. Meeting: IEAGHG 6th Post Combustion Capture Conference (PCCC-6), Virtual Meeting 19th-21st October 2021.
- Oral Presentation: "Mass transfer intensification in the absorber column using 3D printing dynamic polarity packings" Authors: Min Xiao, Moushumi Sarma, Jesse Thompson, Kunlei Liu. Meeting: IEAGHG 6th Post Combustion Capture Conference (PCCC-6), Virtual Meeting 19th-21st October 2021.
- Oral Presentation: "High efficiency destruction of N-nitrosamines in waterwash solutions from CO_2 capture systems" Authors: Keemia Abad, Shino Toma, Saloni Bhatnagar, Kunlei Liu, Jesse Thompson Meeting: IEAGHG 6th Post Combustion Capture Conference (PCCC-6), Virtual Meeting 19th-21st October 2021.
- Oral Presentation: "Effect of Additives on Increasing Solvent Wettability inside the Absorber Column of a Carbon Capture System" Authors: Moushumi Sarma, Saloni Bhatnagar, Keemia Abad, Min Xiao, Kunlei Liu, Jesse Thompson. Meeting: IEAGHG 6th Post Combustion Capture Conference (PCCC-6), Virtual Meeting 19th-21st October 2021.
- Oral Presentation: "Advancing Post-Combustion CO_2 Capture through Increased Mass Transfer and Lower Degradation" Author: Jesse Thompson. Meeting: National Energy Technology Laboratory Carbon Management and Natural Gas & Oil Research Project Review Meeting Virtual Meetings, August 2 through August 31, 2021. The presentation file is available online: https://netl.doe.gov/sites/default/files/netl-file/21CMOG_PSC_Thompson.pdf
- Oral Presentation: "Effect of addition of Catalysts/Additives on CO_2 Absorption Rates via controlled bubble generation in CCS solvents" Authors: Moushumi Sarma, Kunlei Liu, Jesse Thompson. Conference: Fall 2021 Americal Chemical Society National Meeting, 22nd August 2021 Atlanta, GA, USA, (virtual).
- Oral Presentation: "Determination of Surfactants in High pH CO_2 Capture Solvents by Hydrolysis, Derivatization, and GC-MS analysis" Authors: Saloni Bhatnagar, Min Xiao, Kunlei Liu, Jesse Thompson. Conference: Fall 2021 Americal Chemical Society National Meeting, 22nd August 2021 Atlanta, GA, USA, (virtual).
- Oral Presentation: "Matching CO_2 capture solvents with 3D-printed polymeric packing to enhance absorber performance" Authors: Moushumi Sarma, Keemia Abad, Saloni Bhatnagar, Du Nguyen, Samantha Ruelas, Min Xiao, Kunlei Liu, Jesse Thompson. Conference: 15th International Conference on Greenhouse Gas Control Technologies, GHGT-15, 15th - 18th March 2021 Abu Dhabi, UAE (virtual).
- Oral Presentation: "Effect of changes of physical properties on CO_2 capture solvents on its absorption rate ". Authors: Moushumi, Jesse Thompson, Saloni Bhatnagar, Shino Toma, Keemia Abad, Kunlei Liu. Conference: ACS Fall 2020 National Virtual Meeting, August 17 - 20, 2020. The presentation file was uploaded to OSTI and has a DOI identifier of: https://doi.org/10.2172/1732159.
- Oral Presentation: "Modifying Amine Solvent Properties to Increase CO_2 Mass Transfer". Authors: Jesse Thompson, Heather Nikolic, Kunlei Liu. Conference: 5th Post Combustion Carbon Capture Conference (PCCC5), 17th-19th September 2019, Kyoto Japan. The presentation file was uploaded to OSTI and has a DOI identifier of: https://doi.org/10.2172/1763066.
- Oral Presentation: "Advancing Post-Combustion CO_2 Capture through Increased Mass Transfer and Lower Degradation" Authors: Jesse Thompson, Kunlei Liu. Conference: 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting, Pittsburgh, PA, August 26-30, 2019. The presentation file is available through the NETL conference proceedings website at: https://netl.doe.gov/sites/default/files/netl-file/J-Thompson-UKY-CAER-Increased-Mass-Transfer.pdf.
- Oral Presentation: "Decomposition of nitrosamines through electrochemically-mediated reduction on carbon xerogel electrode." Authors: Shino Toma, Jesse Thompson, Xin Gao, Keemia Abad, Saloni Bhatnagar, James R. Landon, Kunlei Liu. Conference: ACS Spring 2019 National Meeting & Exposition, Orlando FL, March 31 – April 4, 2019. Division of Environmental Chemistry, Session: Electrochemical Water Treatment. The presentation file was uploaded to OSTI and has a DOI identifier of: https://doi.org/10.2172/1733231.

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