FEW0225: High-efficiency, integrated reactors for sorbents, solvents, and membranes using additive manufacturing

NETL Carbon Capture Technology Program Review
August 27, 2019

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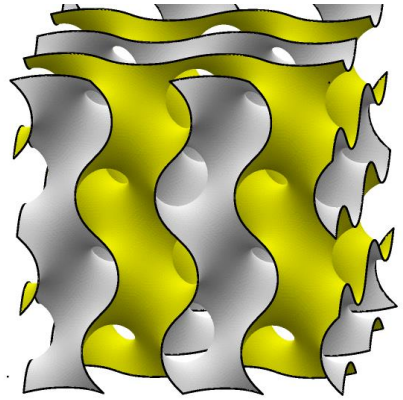
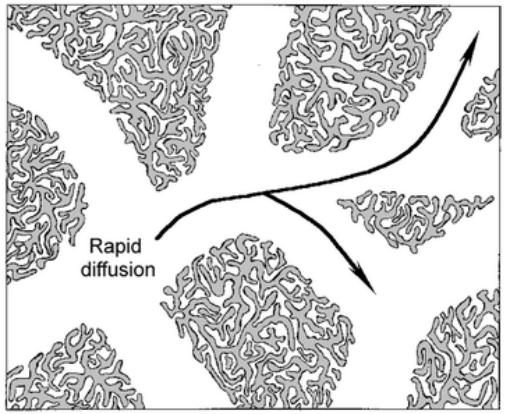
Lawrence Livermore National Laboratory

Goal: more efficient, lower cost reactors for CO_2 capture.

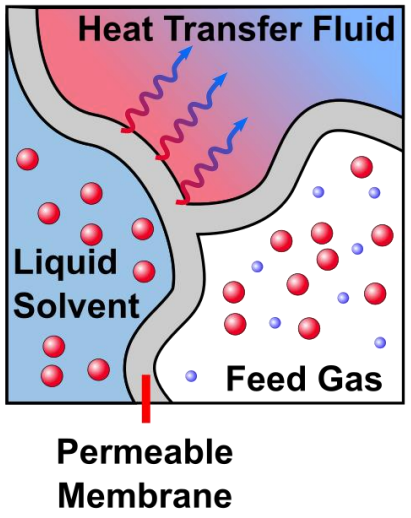
We focus on three design features:



Triply Periodic Minimal Surface (gyroid-like) structures



Hierarchical flow channels



Multifunctional Reactors

Project Plan

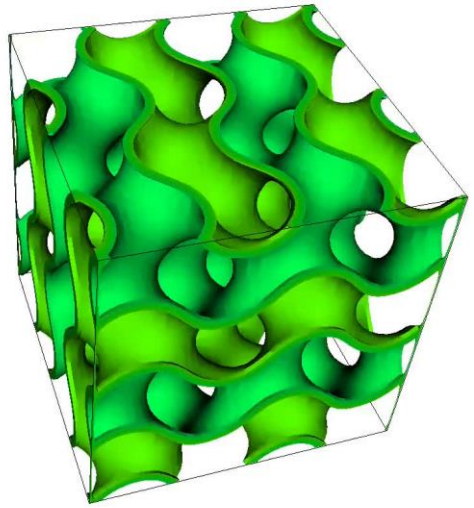
FEW0225: $3.8M over 4 years

	Year 1	Year 2	Year 3	Year 4
Theoretical Assessment	Downselect			
Fabrication Assessment	Proof of concept reactor			
Generation 1 Reactor		Design→	1st-gen design	Prototype demo→
Generation 2 Reactor			Design→	Bench-scale test → Demo design

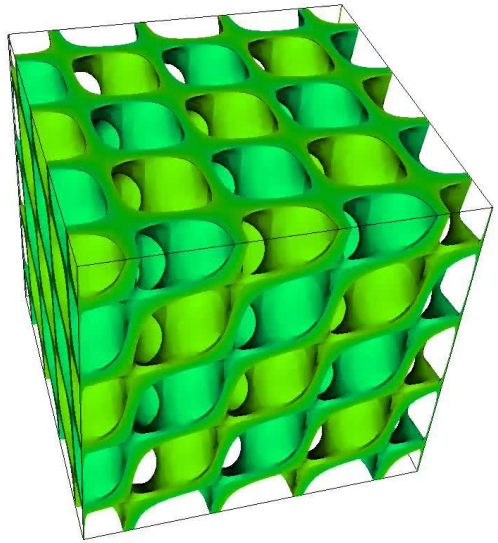
- 10 tasks in 3 tracks
- Downselect to two reactor concepts, developed in series
- Tech transfer targeted for middle of Year 4 for 1st-gen design

TPMS geometries enhance fluid mixing

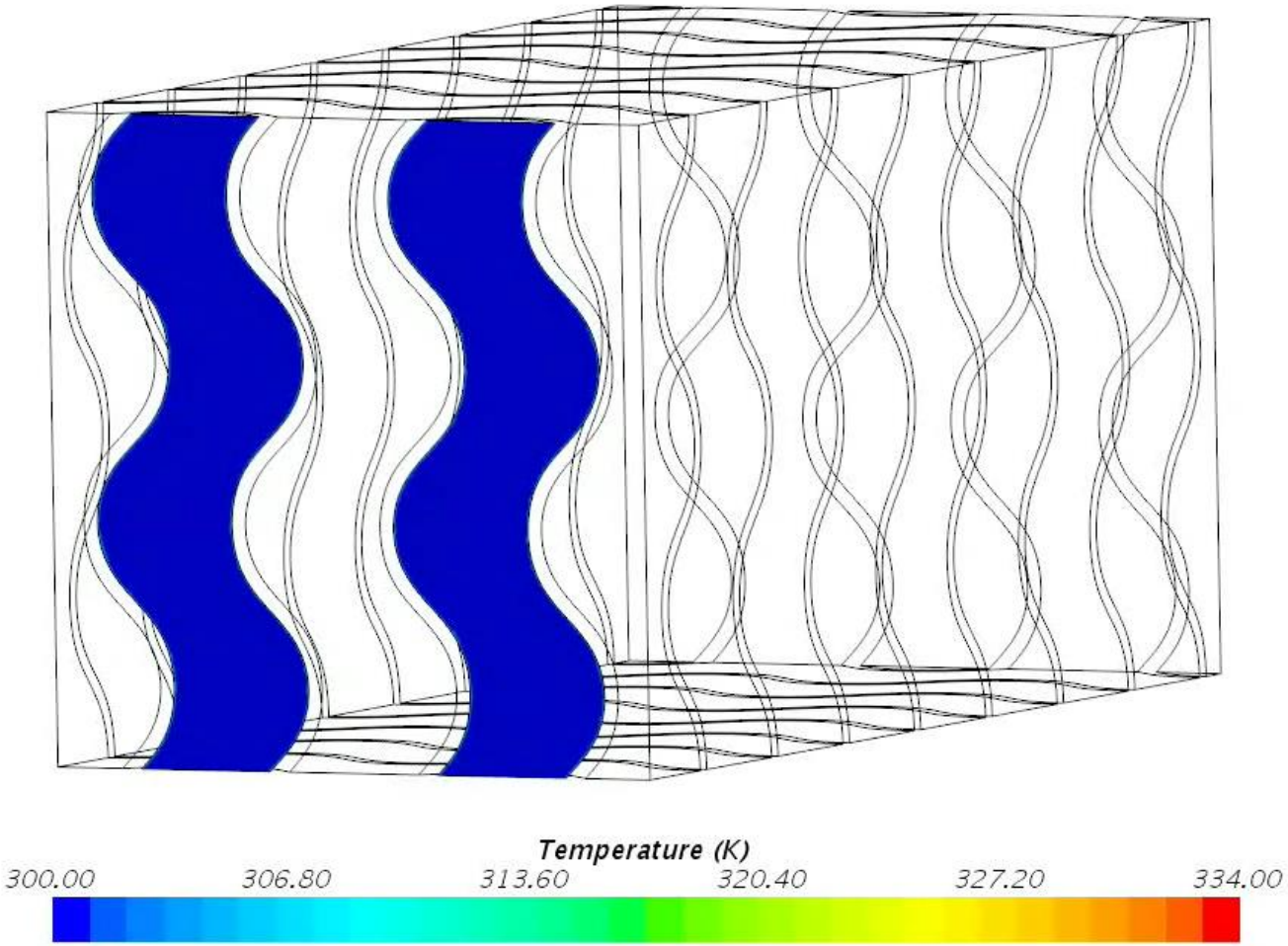
Gyroid



Schwarz-D

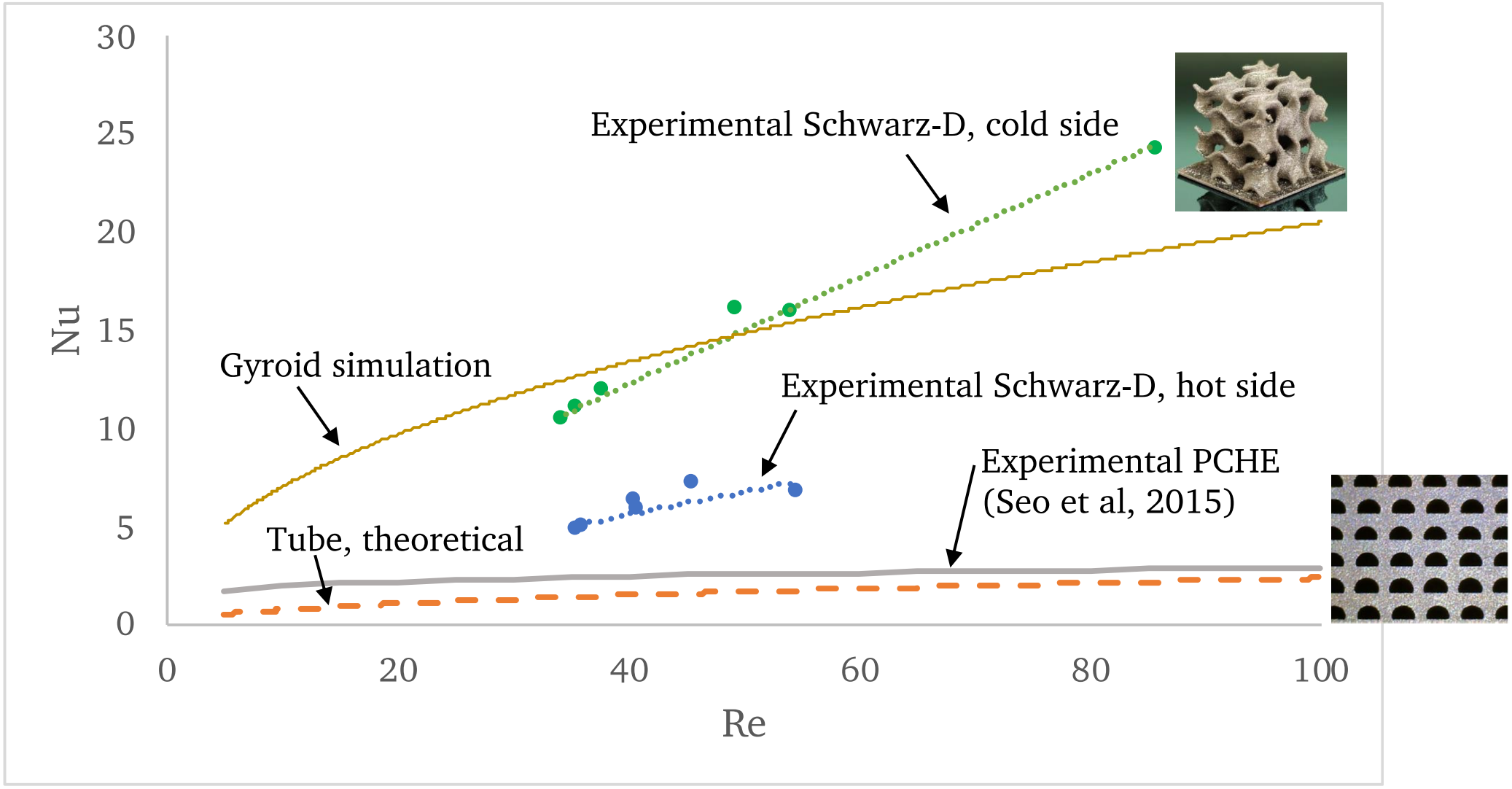


Temperature in Cold Fluid in Countercurrent Heat Exchanger

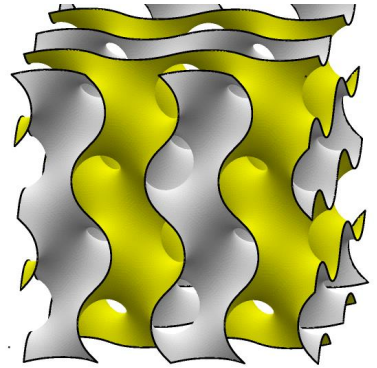


We have confirmed the case for TPMS heat exchangers with simulations and measurements.

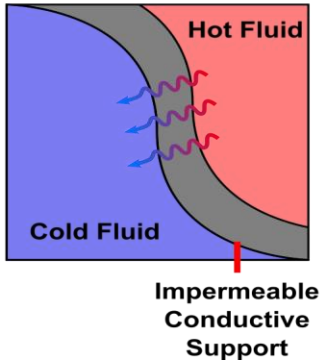
Heat transferred vs. flowrate for TPMS and printed circuit heat exchangers



Many reactor configurations possible with TPMS and additive manufacturing.

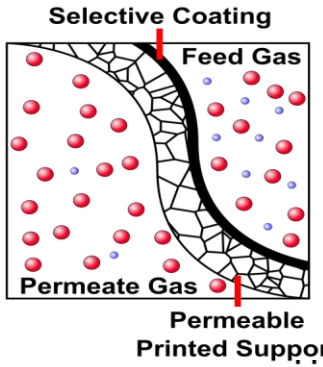


Heat Exchange



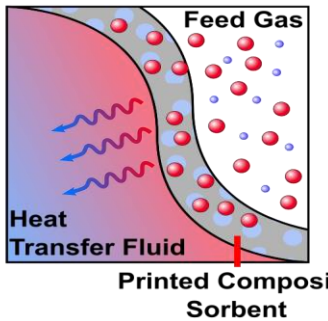
→ Pursued in other work

Gas Separation Membrane



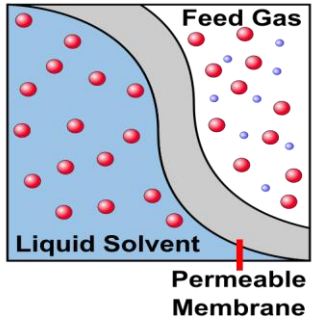
→ Unclear advantage

Gas Absorption Monolith w/ Heat Exchange



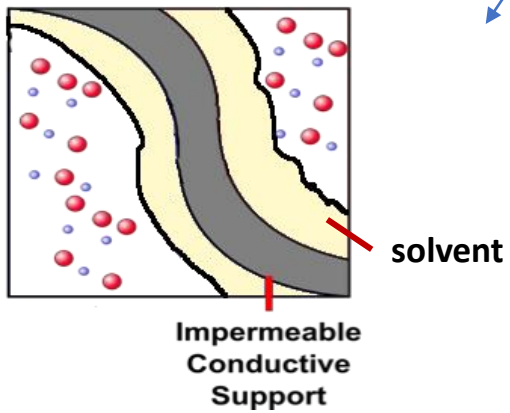
→ Unclear advantage

Membrane Contactor

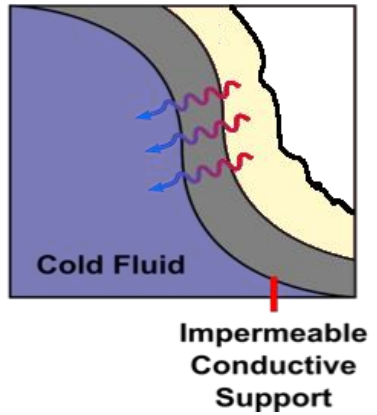


← This work

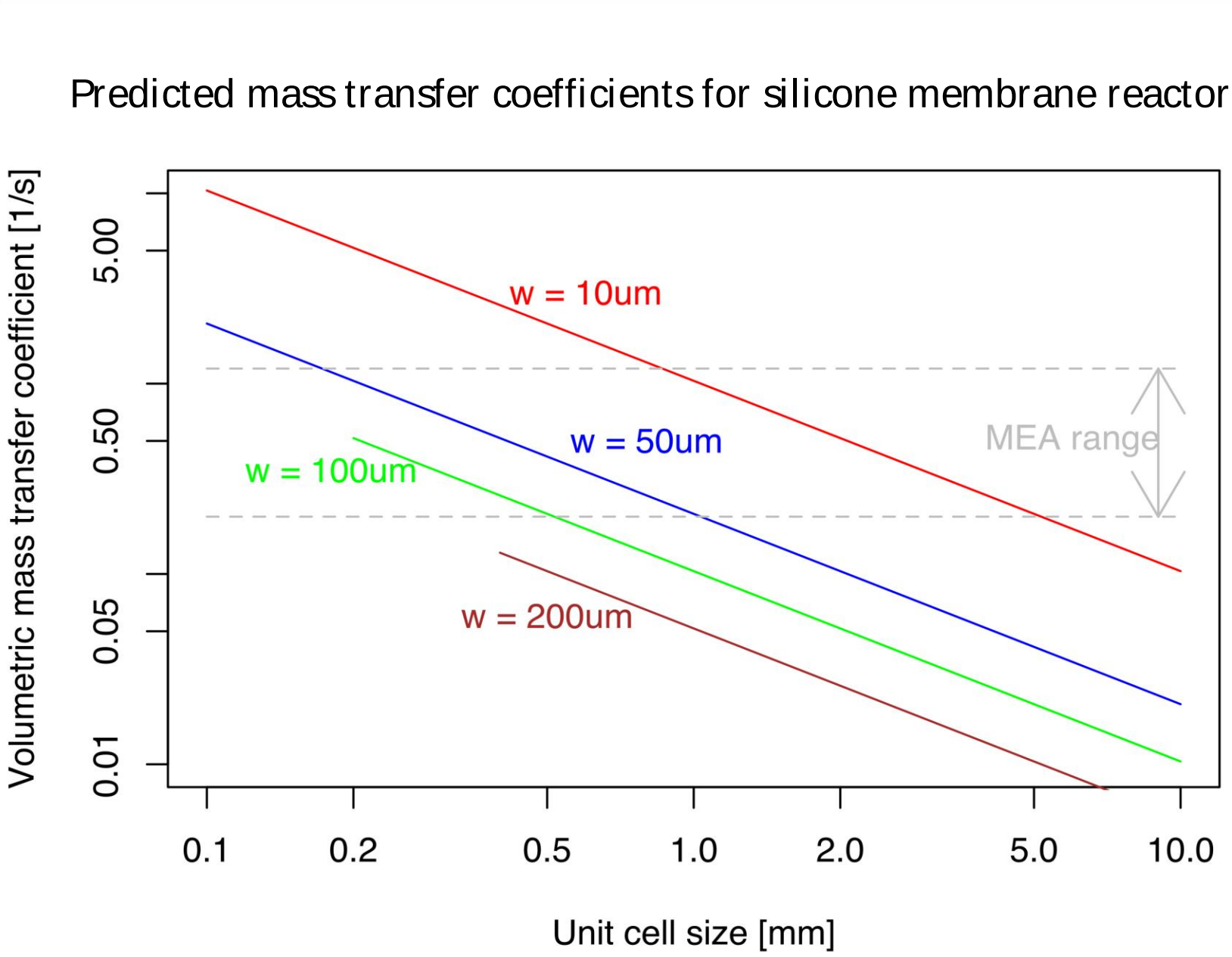
Conventional packing



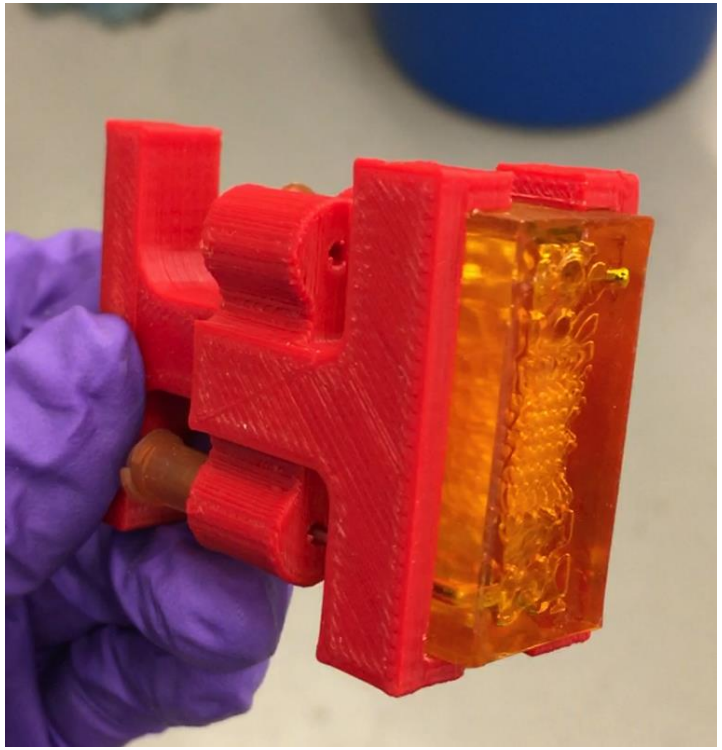
Heat exchange packing

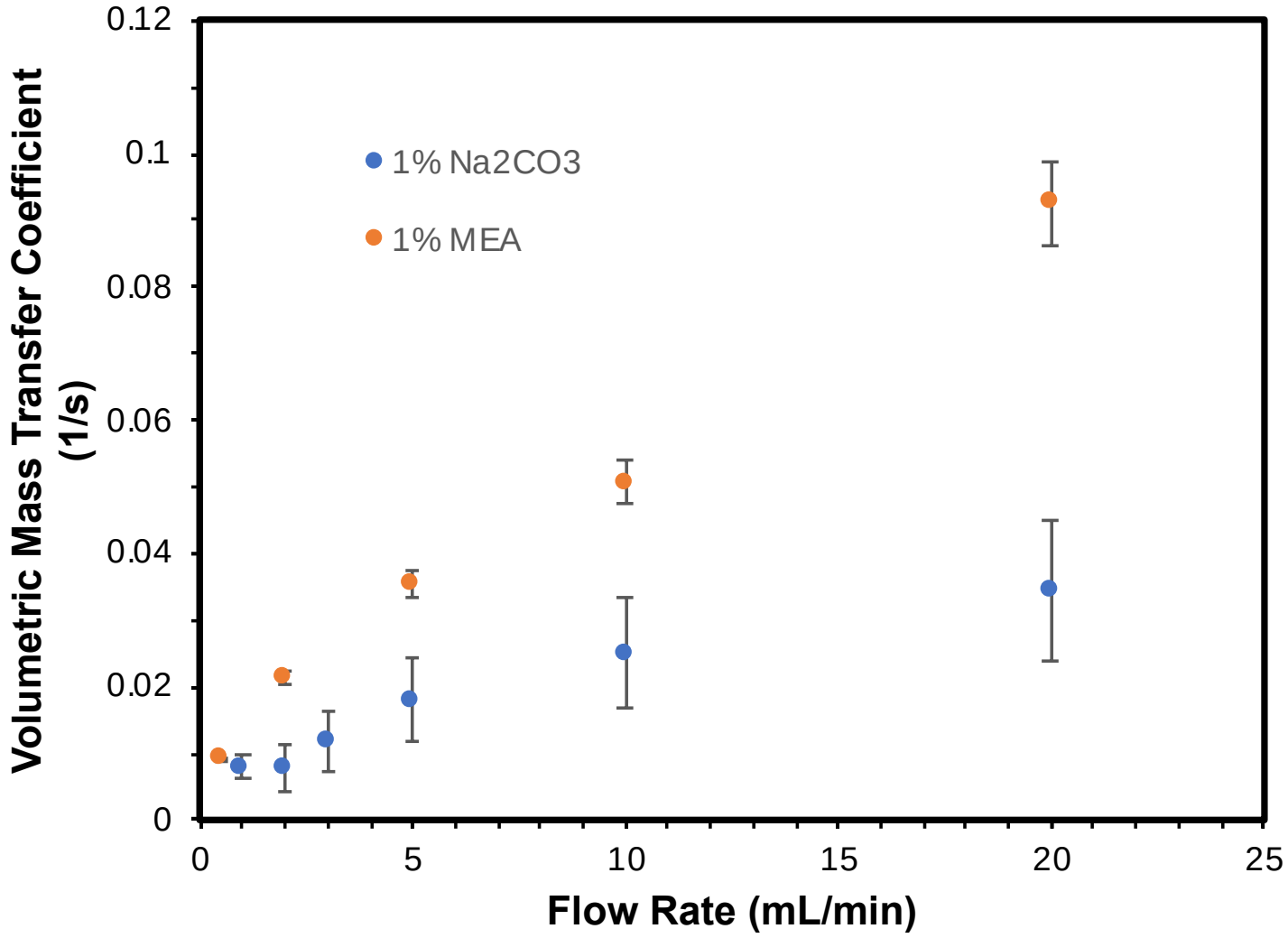


TPMS membrane reactors show theoretical promise

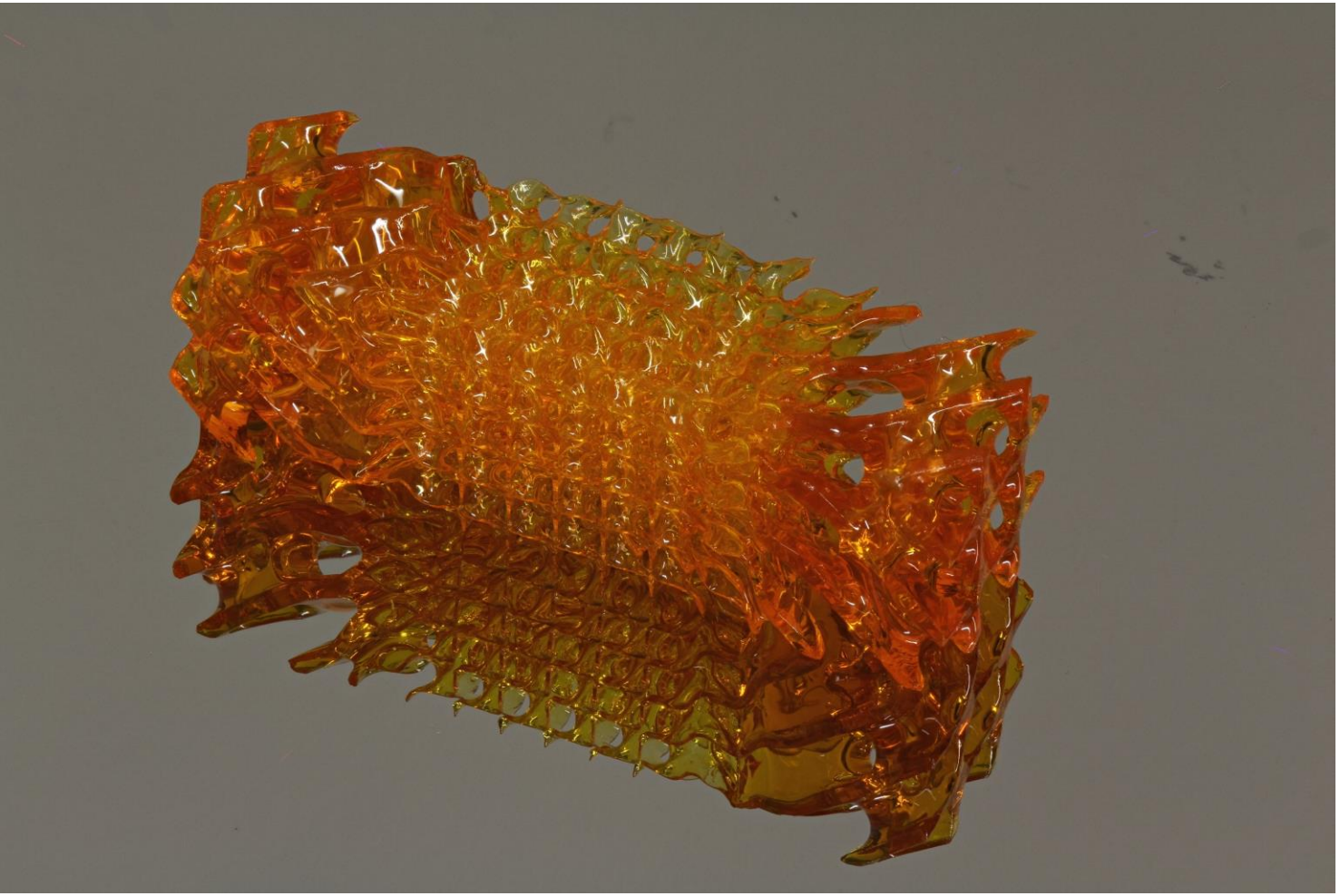


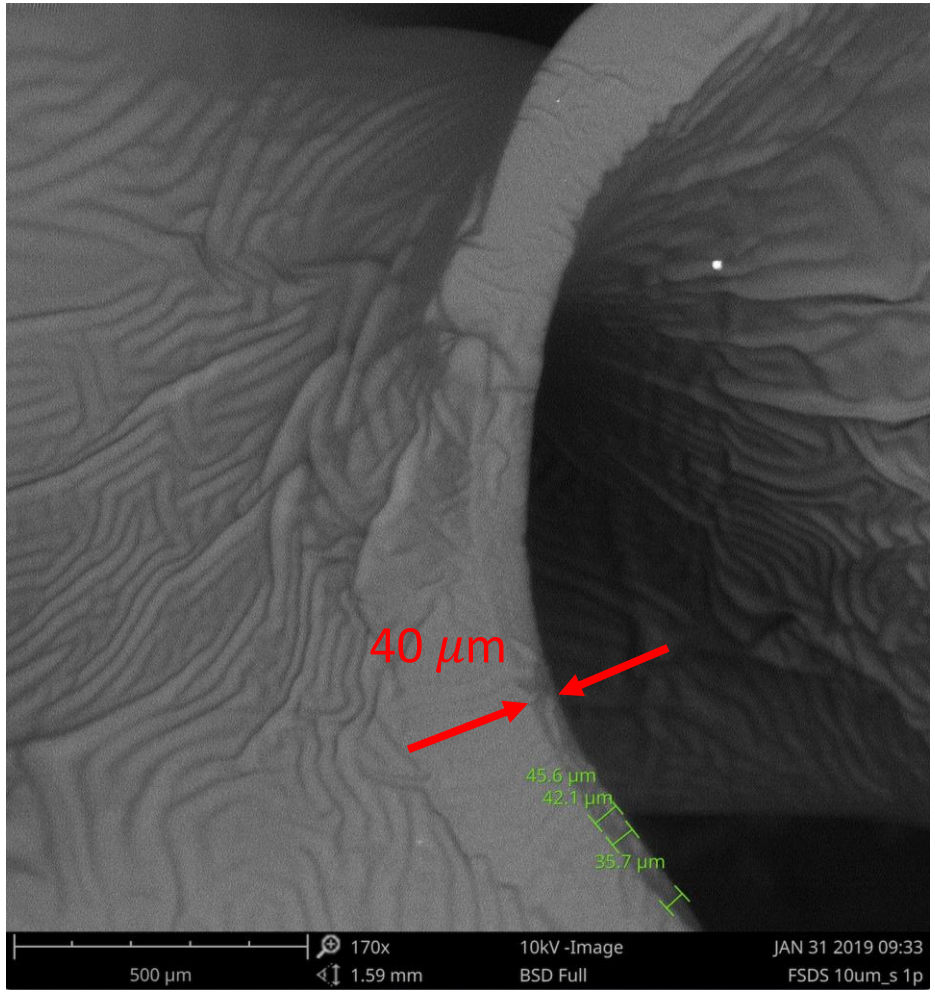
Experimental results slight better than expected for the wall thickness.



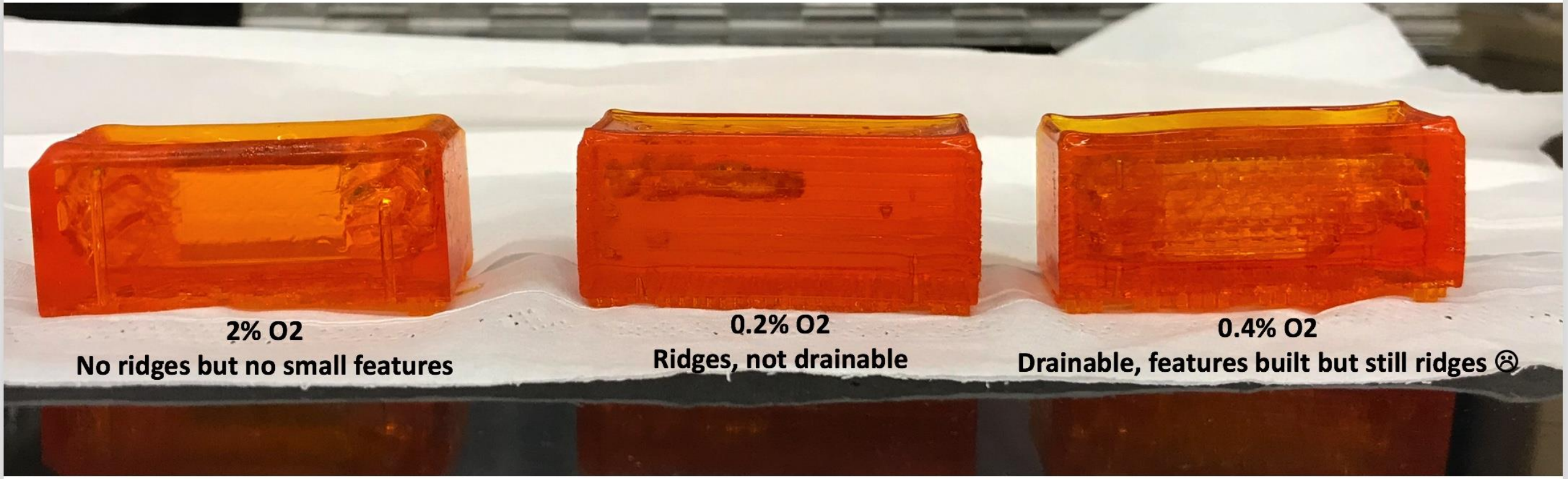


Desired feature sizes are technically achievable.



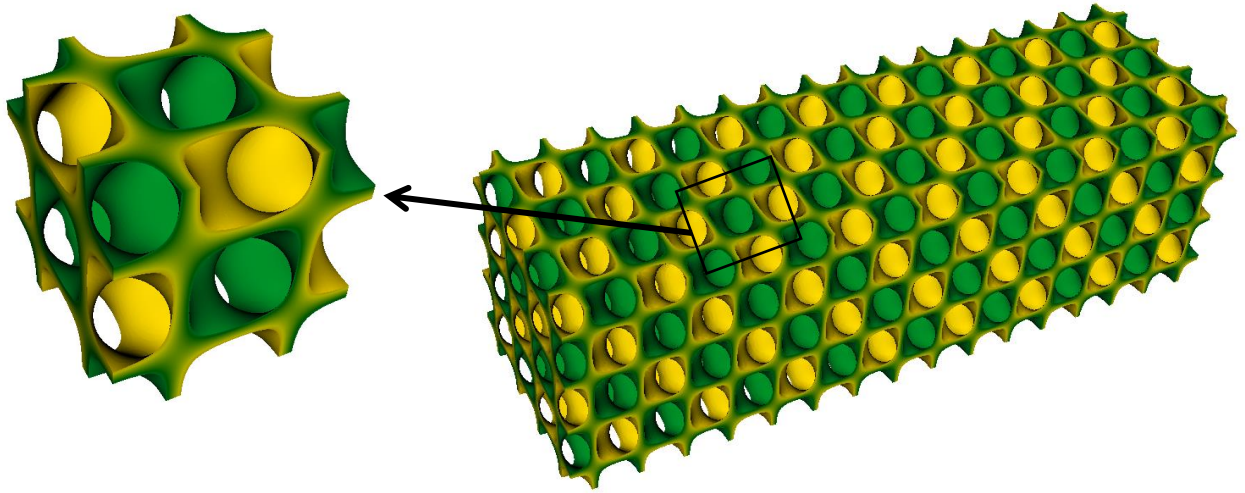


But part-scale fabrication is currently challenging.

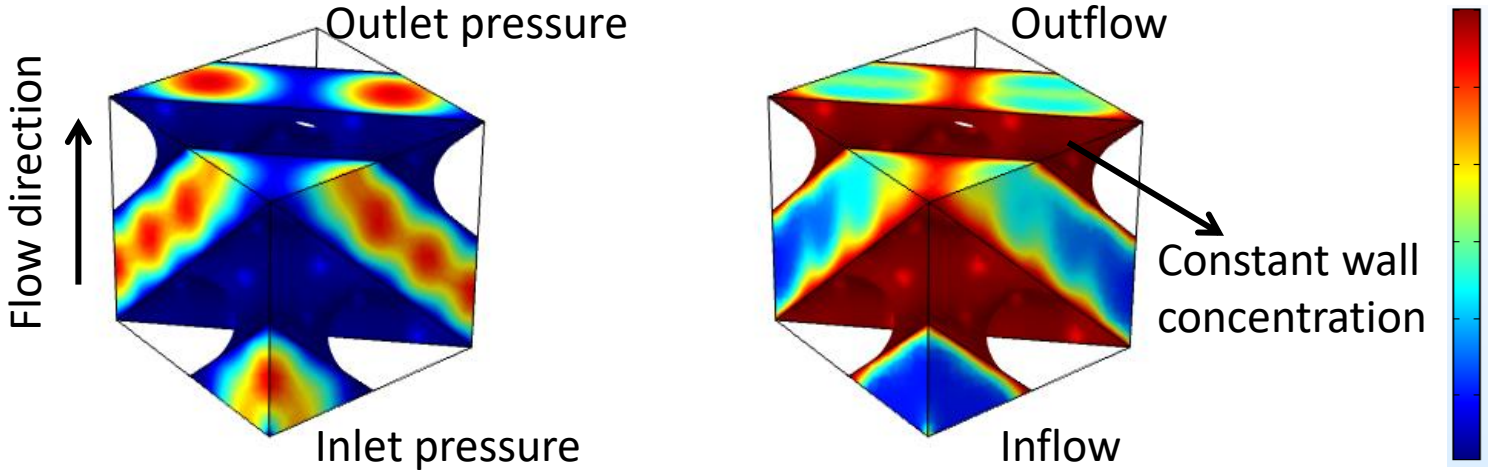


Mass transfer simulations inform TPMS reactor design.

- Geometric properties
  - Void volume per unit cell
  - Surface area per unit cell
  - Hydraulic diameter
- Flow properties
  - Friction factor
- Mass transfer properties
  - Sherwood number



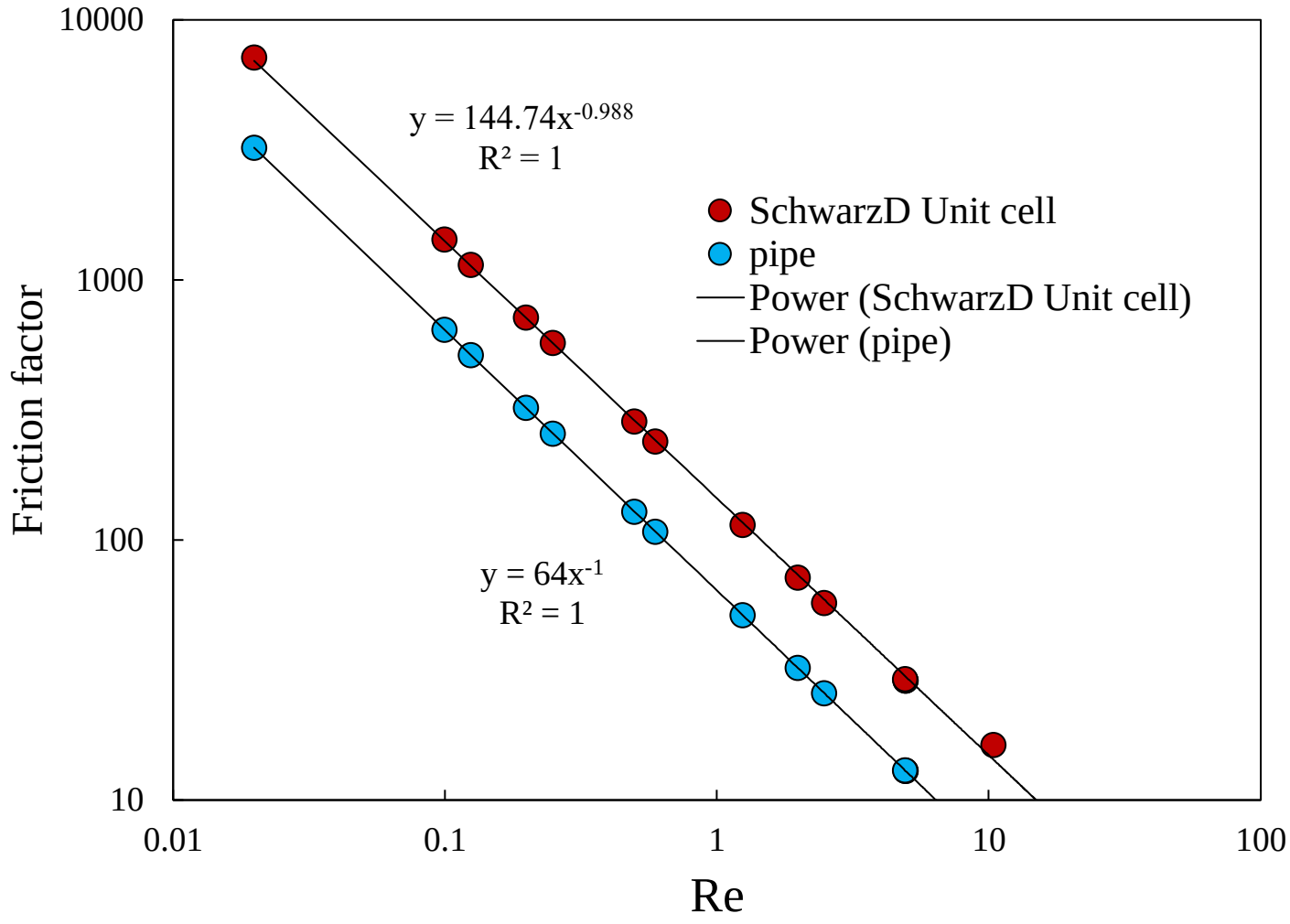
Flow simulation **Mass transfer simulation**



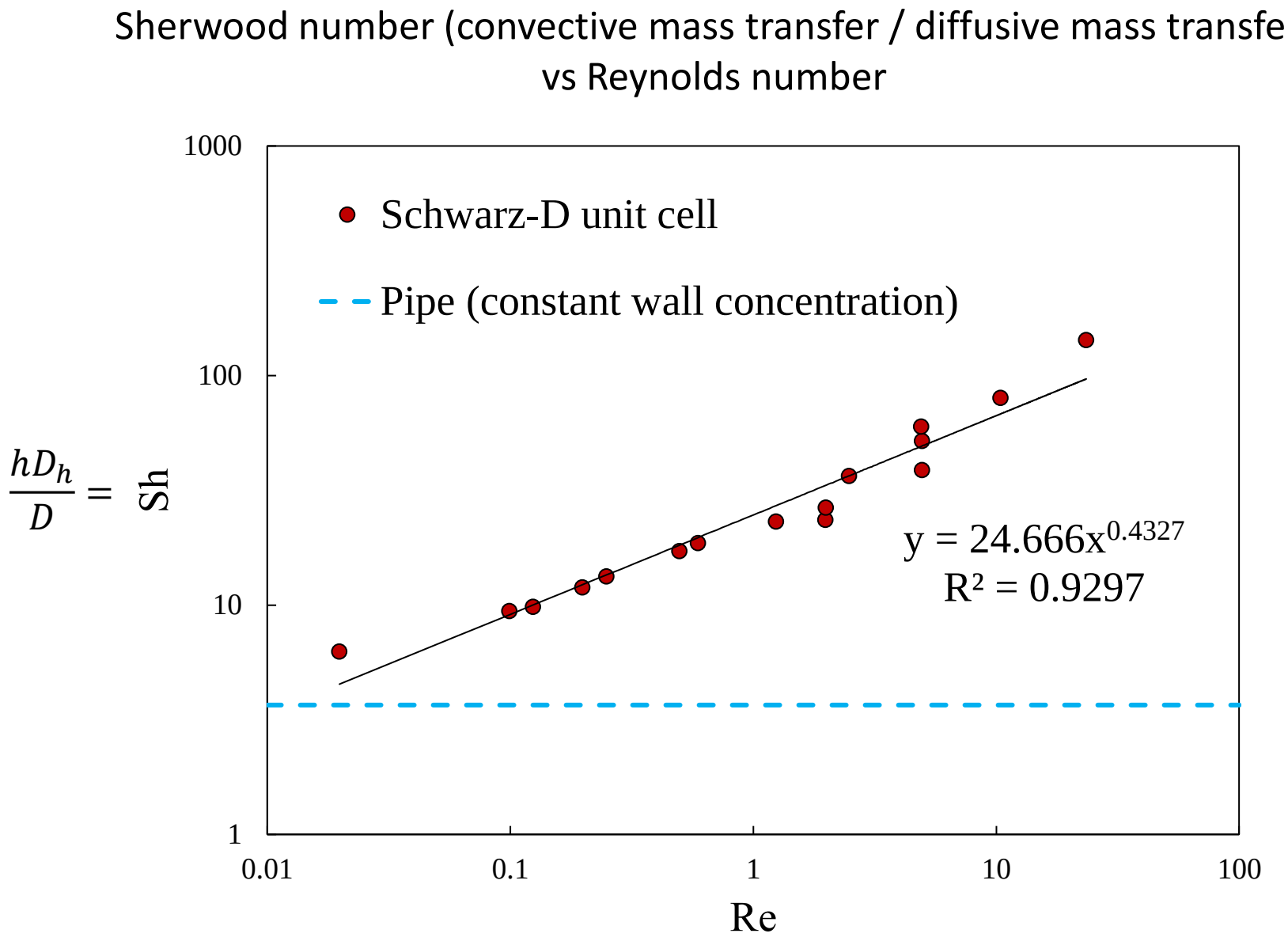
Periodic boundary conditions in all other directions

Pressure drop for a Schwarz D unit cell is about twice that of a pipe (for the same flow rate and hydraulic diameter).

$$\frac{\frac{\Delta P}{L} D_h}{\frac{1}{2}\rho v^2} =$$

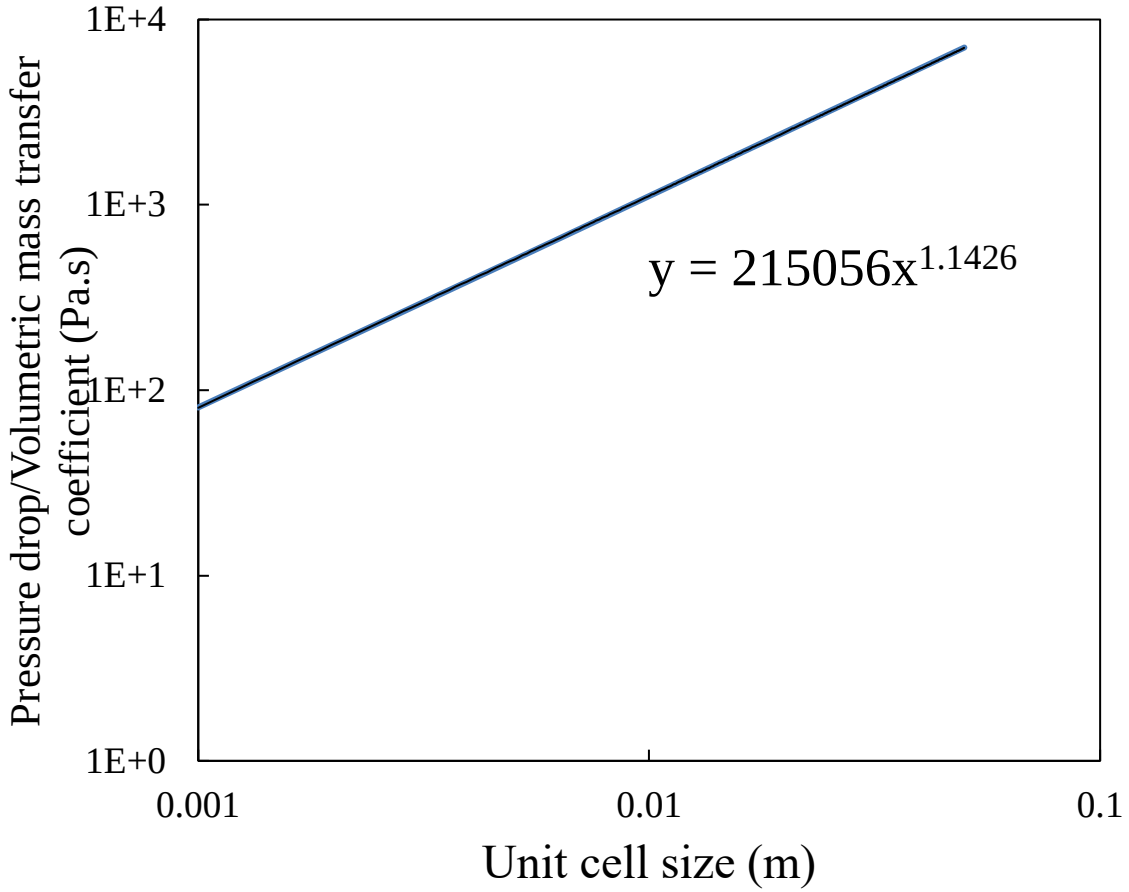


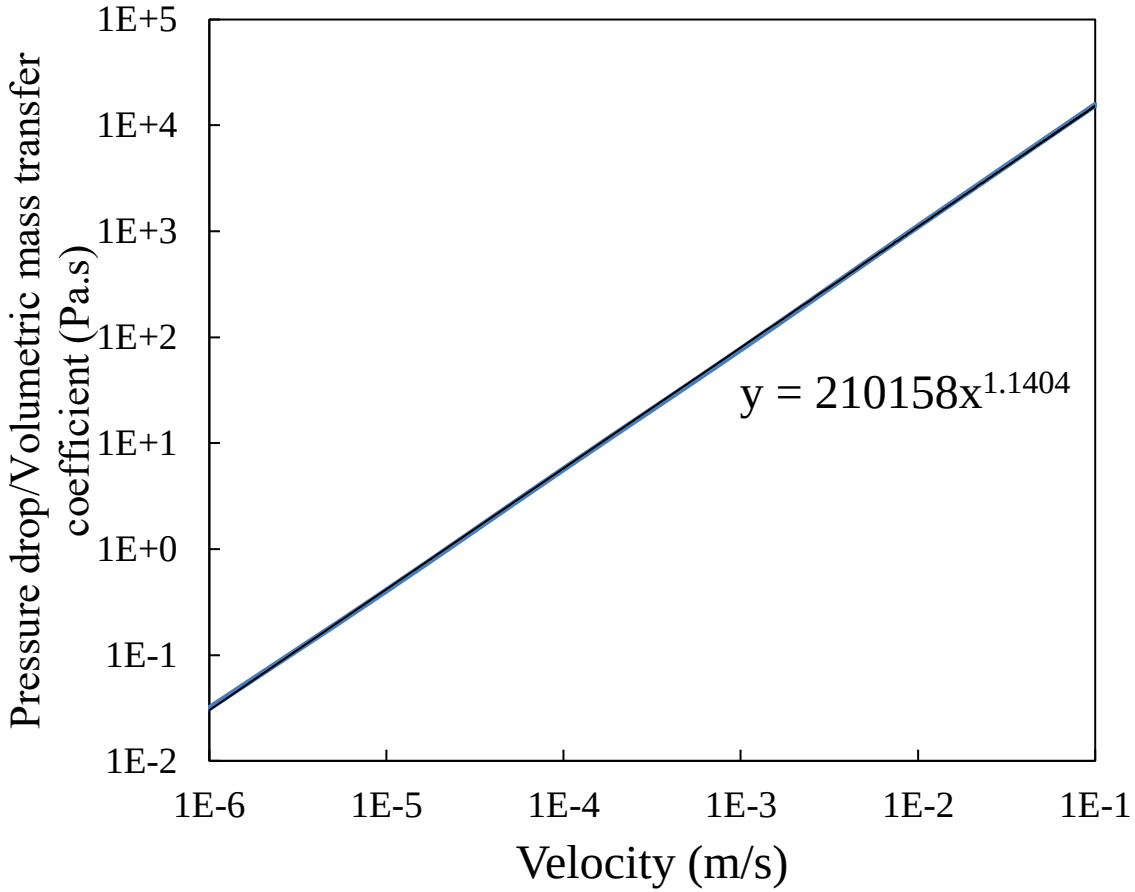
Mass transfer rate improves with liquid velocity faster than for a pipe.



Energy efficiency favors small cell sizes and low velocities

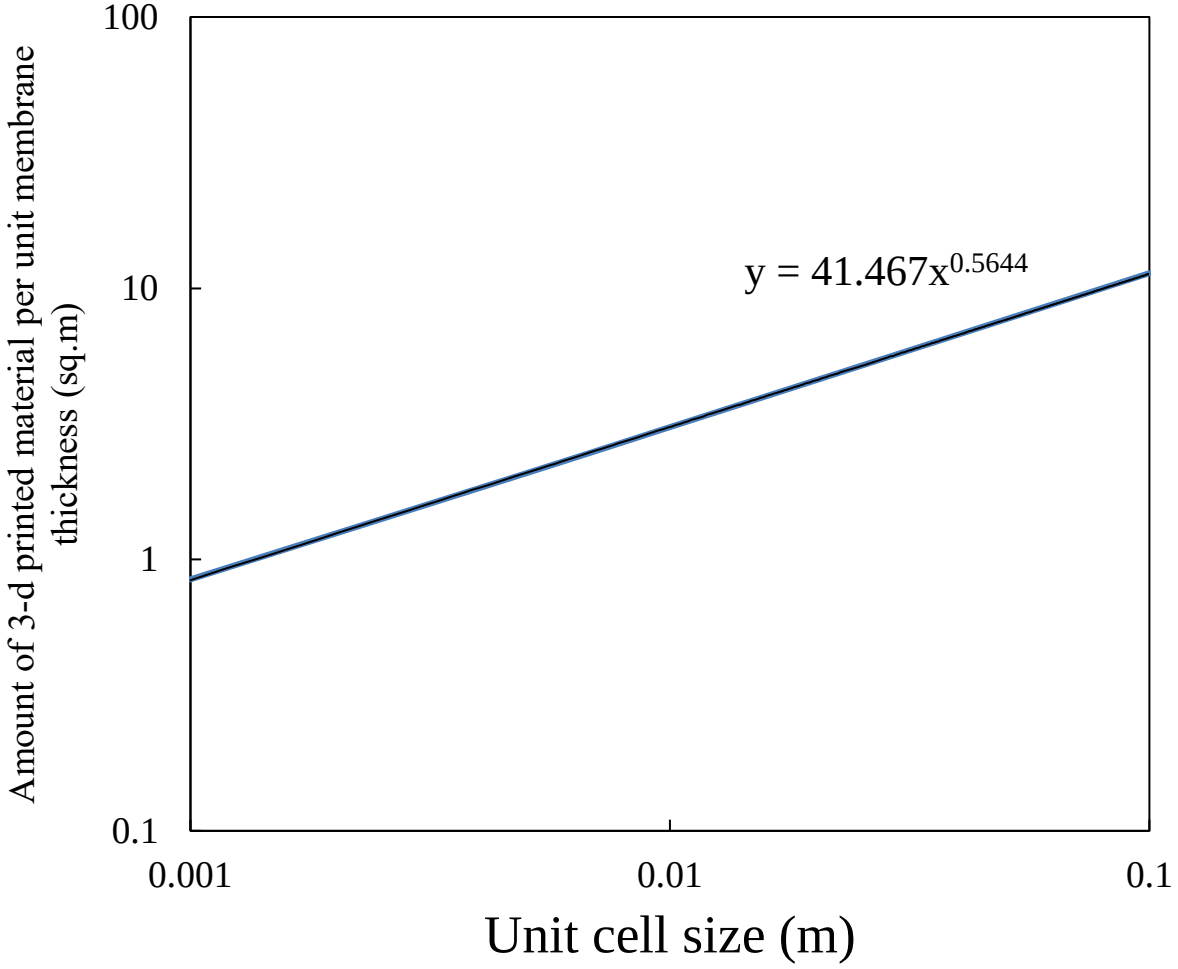
Liquid-side pressure drop in absorber sized for 80% approach to equilibrium

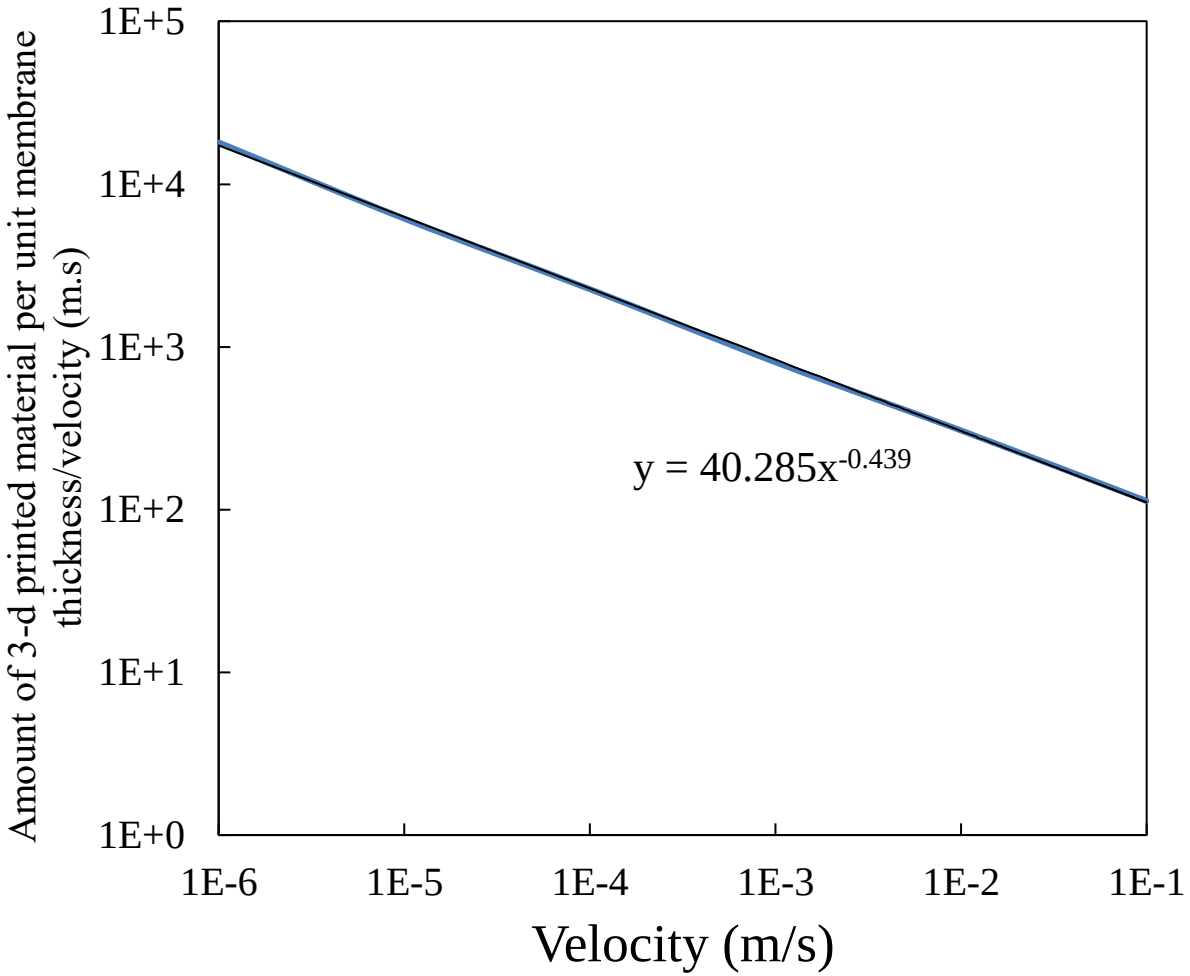




Capital cost favors small cell sizes and high velocities.

Required reactor material per unit CO_2 captured



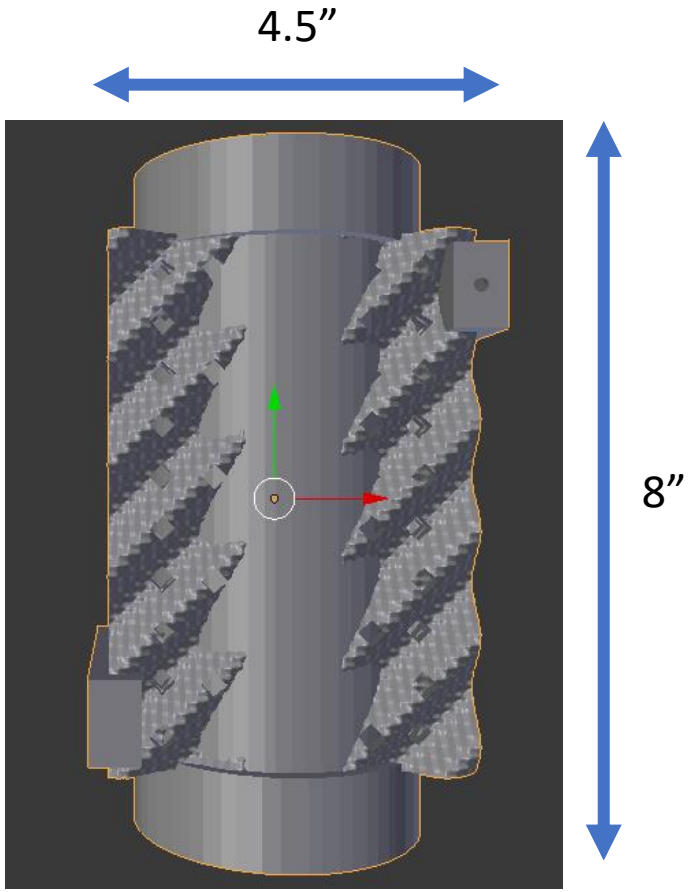


Printed plastic packings allow TPMS geometries, integrated heat exchange.

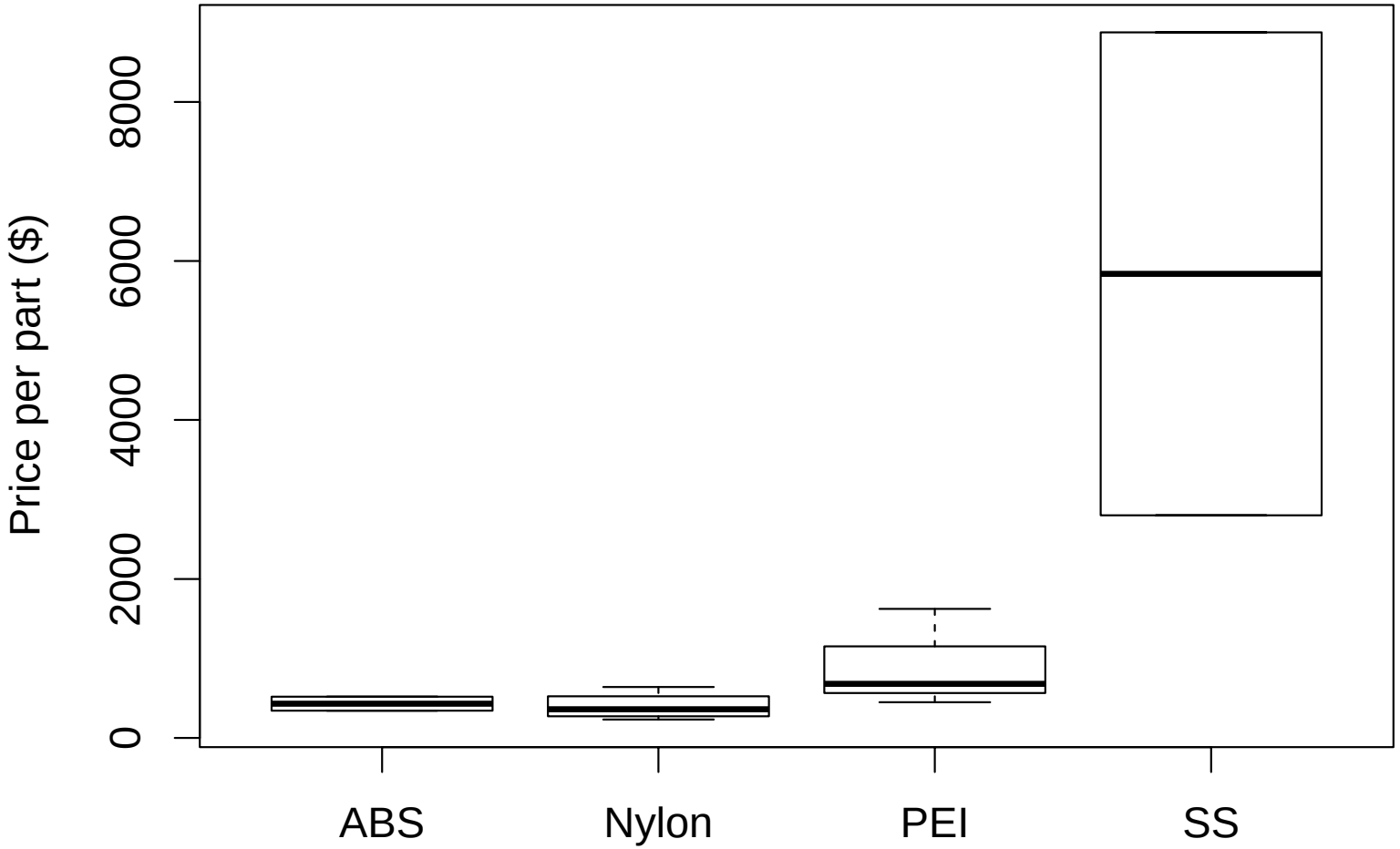
Conventional Stainless Steel Packing

Same geometry in ABS

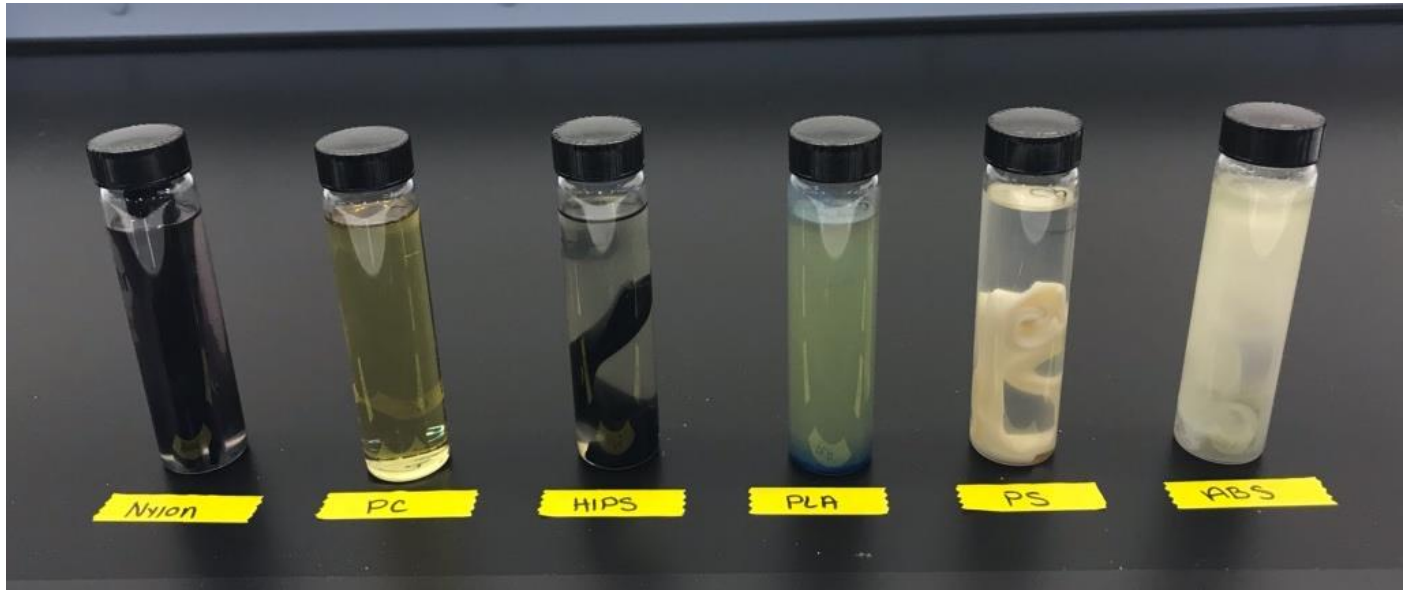
For printed packings, plastic is ~10X cheaper than stainless steel.



Summary of 12 quotes from 3 vendors for the part pictured.



Several printable polymers show promising compatibility.



Material testing @ 48 hours, 100°C in neat 1-amino-2-propanol

Nylon is current leading candidate.

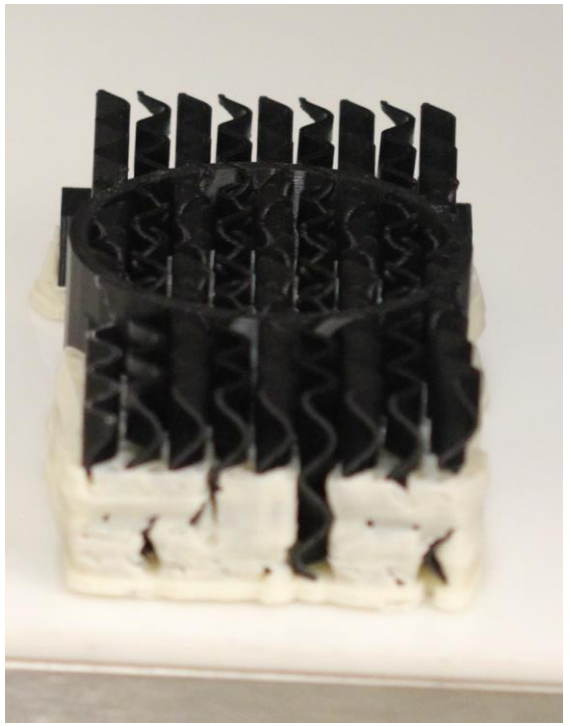
Polymer	Condition @ 48 hr 100C	Condition @ 1000 hr 25C
ABS	Deformed	Stable
Copolyester	Dissolved	Stable
High Impact Polystyrene	Deformed	Stable
Nylon	Stable	Stable
Polycarbonate	Dissolved	Dissolved
Polylactic Acid	Dissolved	Degraded
Polystyrene	Deformed	Stable

Prints in multiple materials have been demonstrated.

ABS

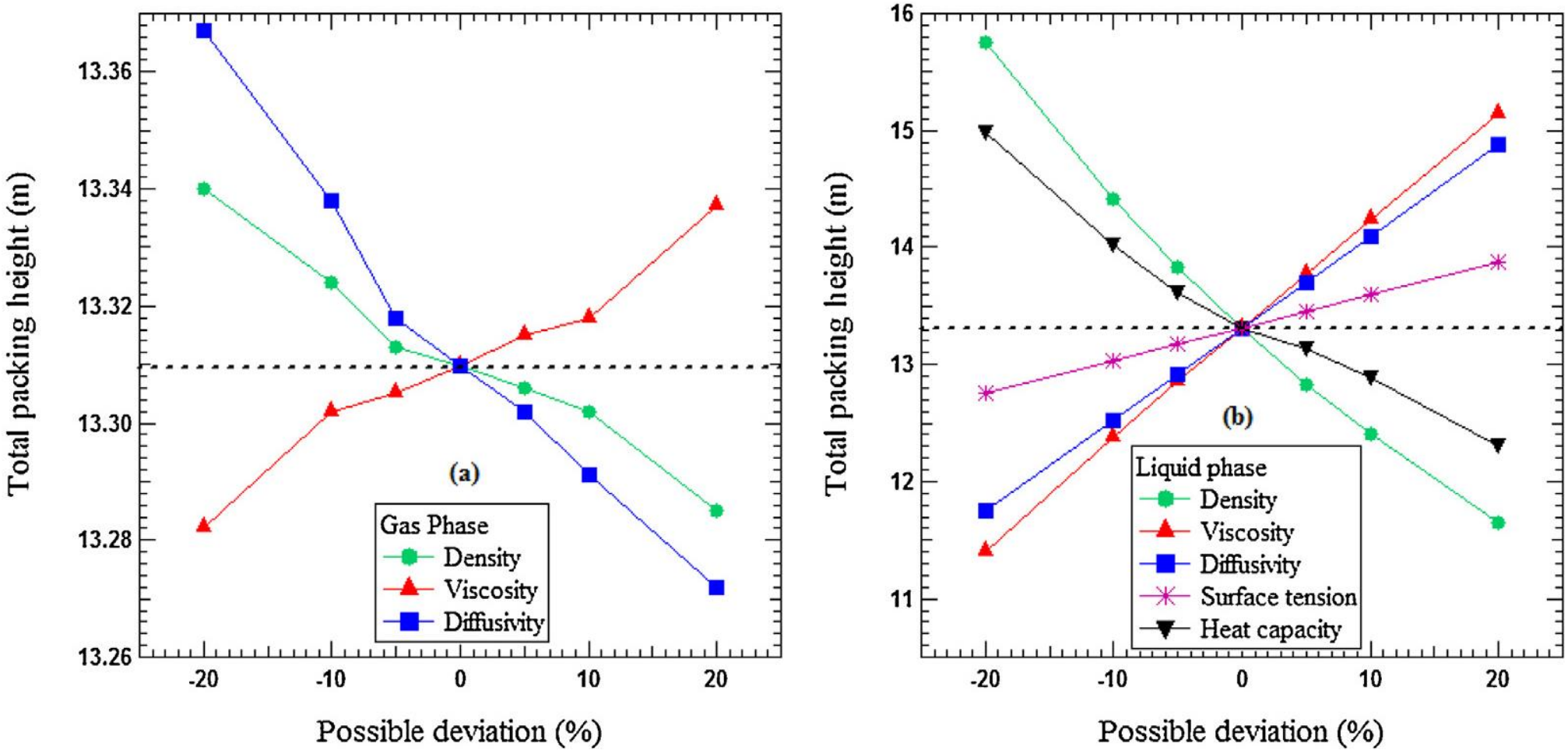
High-Density
Polyethylene

Polycarbonate



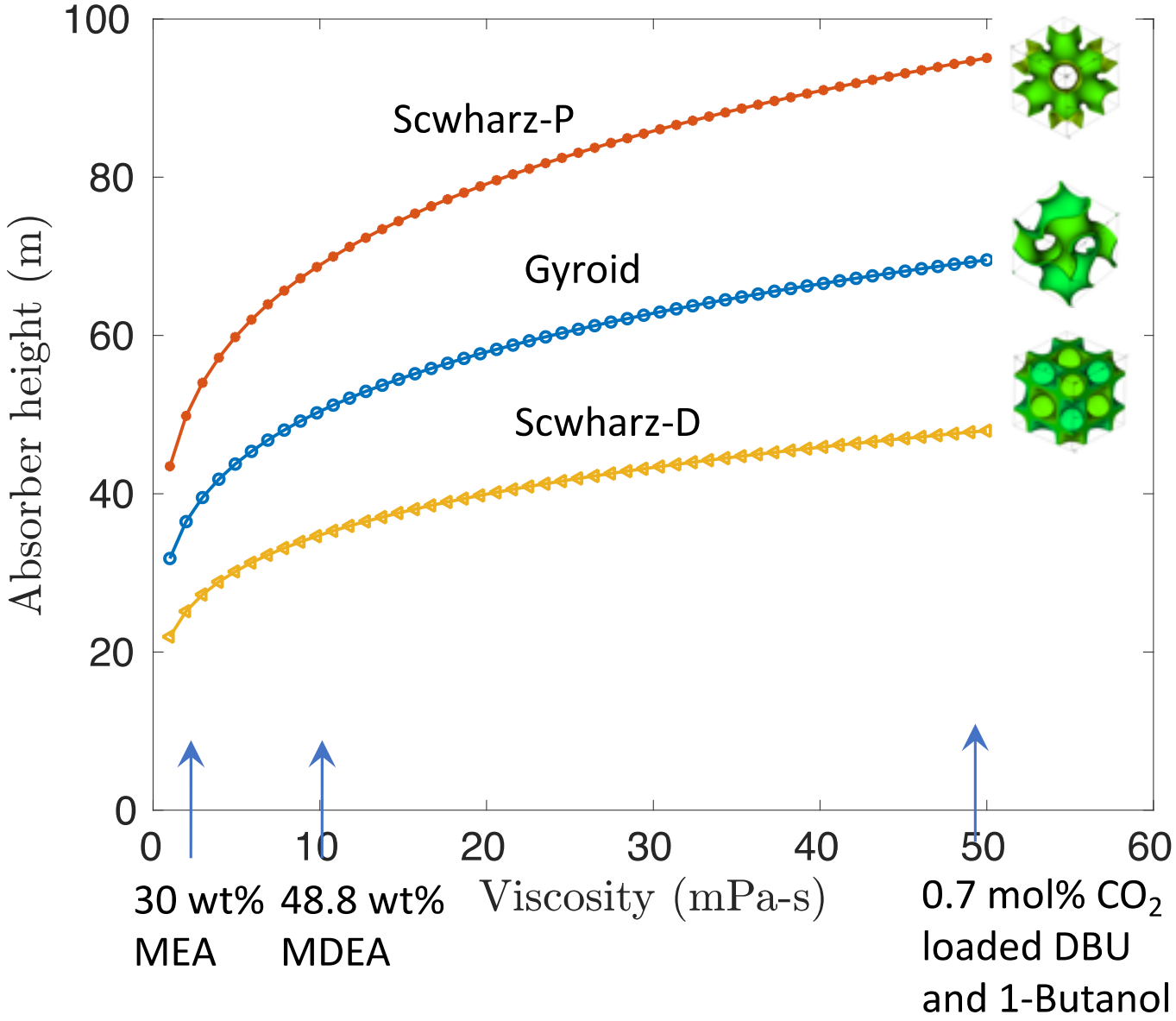
ABS

Models suggest how solvent properties affect absorber size.

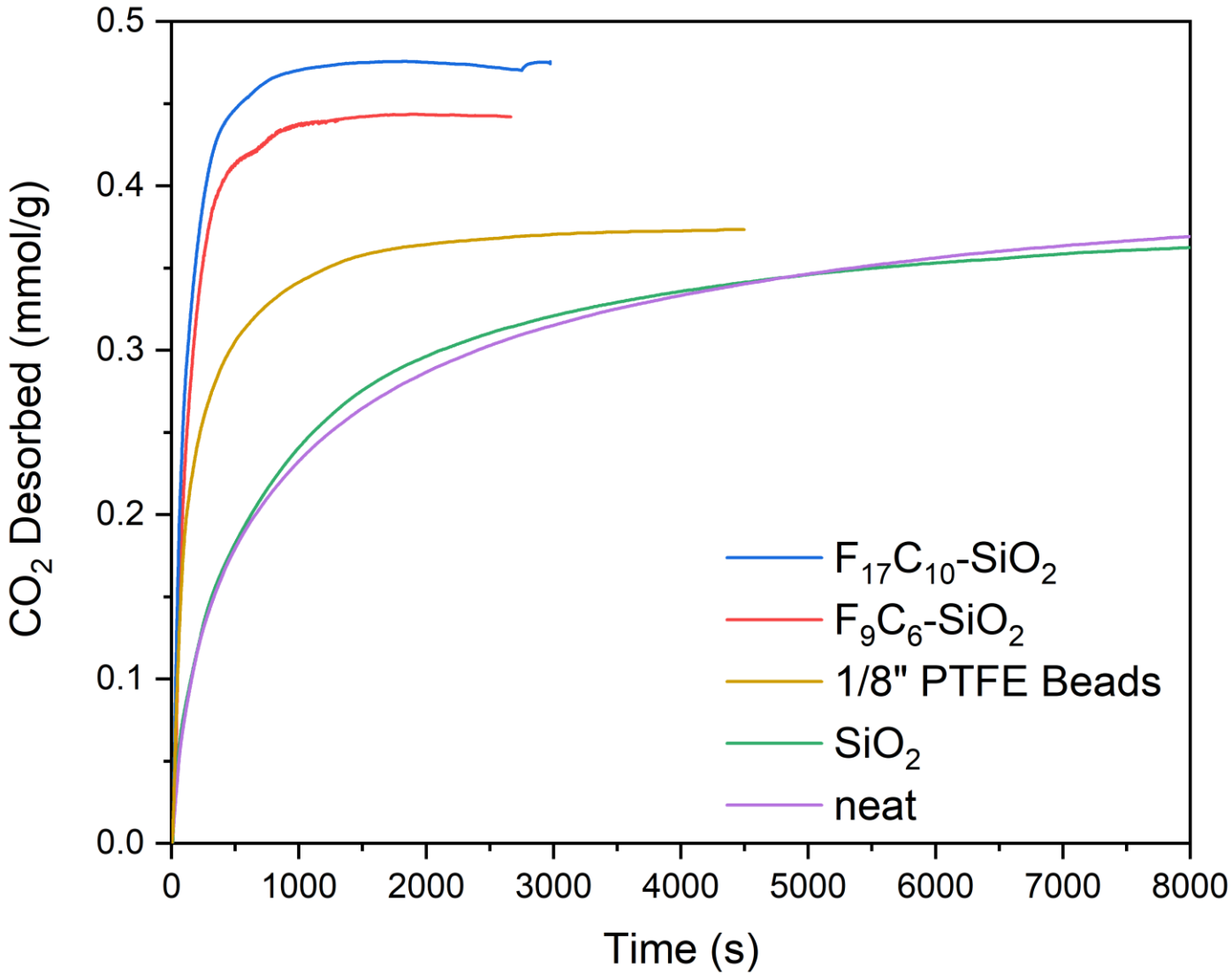


[1] Worrada Nookuea. Impacts of Thermo-Physical Properties on Chemical Absorption for CO2 Capture. PhD thesis, M ̈alardalen University Press, 2016.

Certain geometries may be favored for particular solvent properties (e.g. viscosity).



Hydrophobic stripper packings can speed CO_2 release in polarity-swing solvents



CO_2 desorption kinetics of Koechanol in the presence of various solid antisolvents, when mixture is suddenly heated from 40 to 80 °C.

Conclusions

- TPMS membrane reactors show theoretical promise, but need new material or fabrication strategy.
- For single phase flow, smaller feature sizes are better (to the limits of fabrication).
- Printed plastic packings are viable in terms of materials.
  - Geometry needs to be optimized and compared with conventional packings.
- Hydrophobic surfaces in the stripper are promising for polarity-swing solvents.

Project Team

Joshuah K. Stolaroff, Du Nguyen, Pratanu Roy, Jaisree Iyer, Julie Mancini, Simon Pang, Samantha Ruelas, Matthew Worthington, William Smith, Sarah E. Baker

Acknowledgements

CCSI² Carbon Capture Simulation for Industry Impact

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Questions