Hollow Fiber Post-Combustion Membrane Modules

primary project goal

The National Energy Technology Laboratory's (NETL) Research and Innovation Center (RIC) is developing new, ultra-high-performance membranes and membrane modules for post-combustion carbon dioxide (CO_2) capture. The objective of this effort is to deliver an optimized hollow fiber membrane module for CO_2 separation from industrial sources under near-ambient pressure conditions. A combination of computational fluid dynamics (CFD) modeling and experimental testing are being used to optimize hollow fiber module design to optimize gas flow distribution, minimize pressure drop, and maximize separation efficiency. The team is using computational tools to optimize the design of the module casing and 3D printing to produce test modules for model validation toward a better fundamental understanding of module design.

technical goals

- Reduce the pressure drop in hollow fiber membrane modules for ambient pressure, post-combustion CO_2 capture.
- Increase the gas permeance performance for membrane modules.
- Reduce the time and effort required to prototype new membrane module designs using 3D printing.

technical content

Due to the low driving force for CO_2 separation in post-combustion flue gas and in many industrial carbon capture applications, any membrane-based separation system that does not use flue gas compression must have modules with very low pressure drop.

This effort is a collaboration between NETL (hollow fiber fabrication, hollow fiber module fabrication, and gas permeance testing) and the University of Toledo (membrane module design and modeling). The University of Toledo is conducting CFD simulations to optimize the configuration of hollow fiber membrane modules for post-combustion CO_2 capture. Parameters such as module size, hollow fiber size, flow configurations, packing configurations, and sweep can be varied to minimize pressure drop and maximize separation efficiency. Initial work focuses on how packing of hollow fiber membranes near the solid wall of an enclosing case affects fluid flow and performance. The work also is being extended to randomly packed fiber bundles for comparison to allow determination of both the effect of gaps between the bundle and wall and the effect of random fiber packing on module performance. The results will provide a basis for establishing module manufacturing specifications. Later work is aimed at addressing the use and effect of multiple fiber tows to form hollow fiber bundles. Fiber tows are groups of up to 100 fibers that move through the membrane manufacturing process together and then are used to build a module fiber bundle. Use of fiber tows creates non-uniform fiber packing that can be detrimental to performance. Further work is focused on optimizing the module casing design, including parameters such as the location and geometry of fluid distribution manifolds, as well as internal shell baffling.

CFD models were developed and used to solve using square- and triangle-packed fiber bundles. These simplified models were developed in such a way that they

program area:
Point Source Carbon Capture

ending scale:
Bench Scale

application:
Post-Combustion Power Generation PSC

key technology:
Membranes

project focus:
Hollow Fiber Membrane Modules

participant:
National Energy Technology Laboratory–Research and Innovation Center (RIC)

project number:
FWP-1022402 (Task 11)

predecessor project:
2020 Carbon Capture FWP

NETL technical portfolio lead:
David Hopkinson
david.hopkinson@netl.doe.gov

NETL principal investigator:
David Hopkinson
david.hopkinson@netl.doe.gov

partners:
University of Toledo

give the same performance predictions as a full 3D simulation of filled-in square-packed fiber bundles, but with greatly reduced computational requirements. These models capture the effects of poor fiber packing at the interface with the casing on module performance. The solution domains for these modules and the equivalent planar bundle (EPB) are shown in Figure 1. The blue line in the figure separates the bundles into two domains: (1) the fibers closest to the wall/casing (C2/P2) and (2) the rest of the fibers (C1/P1).

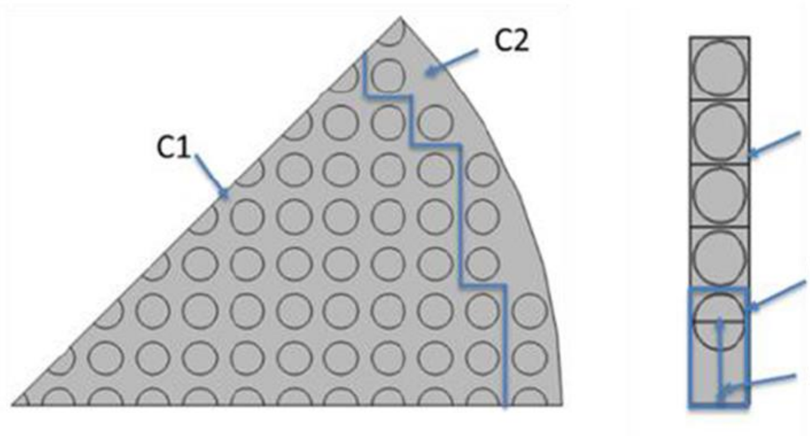
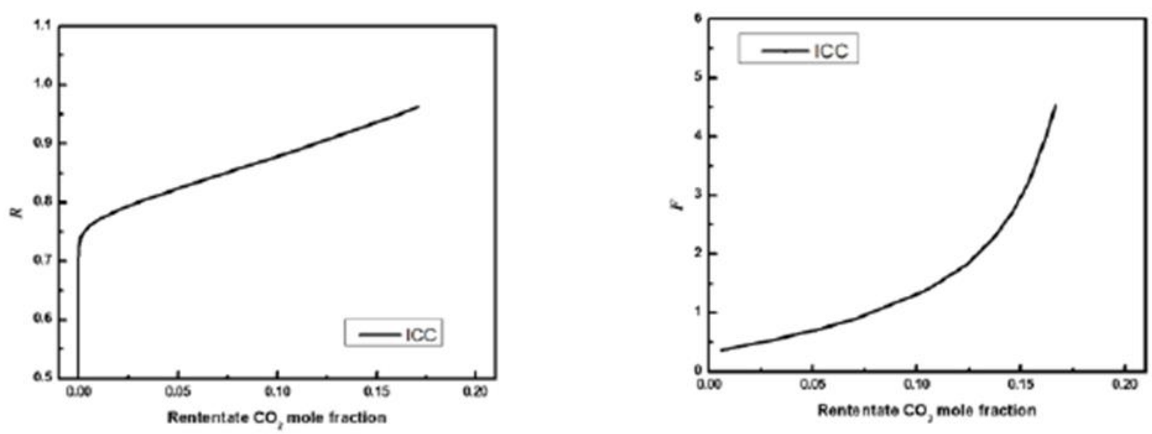
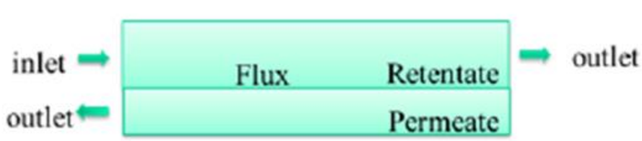


Figure 1: Illustration of circular (left) and planar (right) computational domains.

Simulations were performed over both 3D and EPB domains using a feed gas with 20% CO_2 at a pressure of 2 bar. The performance metrics of these modules, as well as the performance curves of an ideal counter current (ICC) module, are shown in Figure 2. For these metrics, the retentate recovery (R) is indicative of the operational energy costs, while the feed flow rate (F) is indicative of the capital costs of the membrane. R and F are plotted against CO_2 mole fraction in Figure 2. In addition, the performance curve for the 3D square domain is compared to those of the simplified domains in Figures 3 (triangular) and 4 (EPB), respectively.



$$\text{Retentate Recovery } (R) = \frac{\textit{Retentate mole flow rate}}{\textit{Feed mole flow rate}} \qquad F = \frac{\text{Feed flow rate}}{Q * a * P}$$



Q = CO_2 permeance
a = Surface area
P = Feed pressure

Figure 2: Module performance metrics.

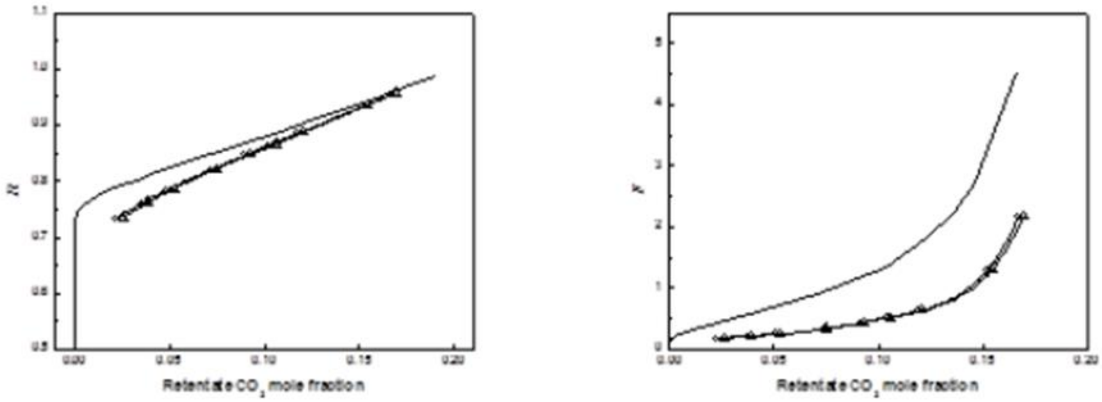


Figure 3: R (left) and F (right) versus CO_2 mole fraction for 3D square- and triangular-packed fiber bundles (circles = square packing; triangles = triangle packing) plotted against ICC.

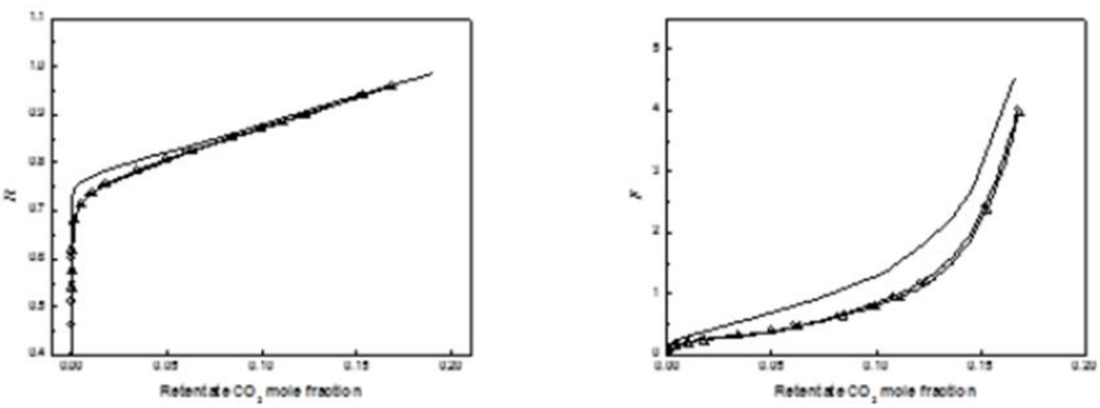


Figure 4: R (left) and F (right) versus CO_2 mole fraction for 3D square-packed and EPB domains (circles = square packing; triangles = EPB) plotted against ICC.

Based on these results, NETL plans to continue with modeling these support structures through two additional subtasks: (1) studying axial diffusion effects to better understand when such diffusion is detrimental to membrane performance, and (2) development and testing of 3D-printed modules for experimental performance measurements in order to validate the models developed thus far.

technology advantages

- Improved design of hollow fiber modules for ambient pressure separations.
- Rapid design and fabrication of test modules.

R&D challenges

- Optimizing geometry for minimizing concentration polarization, module length, and dead space while maximizing packing density.
- Achieving representative module performance in a lab-scale configuration.

available reports/technical papers

N/A.