



CO₂-philic Block Copolymers with Intrinsic Microporosity (BCPIMs) for Post-combustion CO₂
Capture

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Executive summary

Large-scale fabrication of nanofilm nanocomposite membranes has been a major challenge, limiting their practical applications for post-combustion carbon capture. We demonstrate, for the first time, the roll-to-roll fabrication of nanofilm nanocomposite (NFN) membranes based on amorphous poly(ethylene oxide) (*a*PEO), poly(ethylene glycol) dimethyl ether (PEGDME), and UiO-66-NH₂ nanoparticles (NPs), enabled by the hydrogen-bond-induced interfacial compatibility. The membrane exhibits pure-gas CO₂ permeance of 3700 GPU and CO₂/N₂ selectivity of 57 at ~23 °C, surpassing state-of-the-art commercial membranes. This report summarizes testing of this membrane using real flue gas at the National Carbon Capture Center (NCCC). The superior separation properties and stability suggest their potential for practical applications. This work has been published in *Journal of Membrane Science*, 756, 125807 (2026), doi.org/10.1016/j.memsci.2026.125807

Background

Membrane technology has emerged as an exciting platform for post-combustion CO₂ capture from fossil fuel-derived flue gases due to its intrinsic advantages, including high energy efficiency, absence of chemical wastes, excellent scalability, and simple operation and maintenance [1-5]. Membranes with high CO₂ permeance (>1500 GPU, where 1 GPU = 10⁻⁶ cm³(STP) cm⁻² s⁻¹ cmHg⁻¹) and high CO₂/N₂ selectivity (>30) are desirable, as flue gas streams have enormous volumes and low CO₂ partial pressures (0.04–0.13 atm) [6, 7].

Herein, we develop nanofilm nanocomposite (NFN) membranes with selective layers of 90–190 nm using a roll-to-roll dip-coating process (Fig. 1a), achieving superior CO₂/N₂ separation performance. The selective nanofilms comprise *a*PEO with molecular weights of 200 – 400 kDa (synthesized by atomic transfer radical polymerization or ATRP), PEGDME (240 Da), and UiO-66-NH₂ NPs (45 – 85 nm), on top of a dopamine-modified polydimethylsiloxane (*d*PDMS) gutter layer.

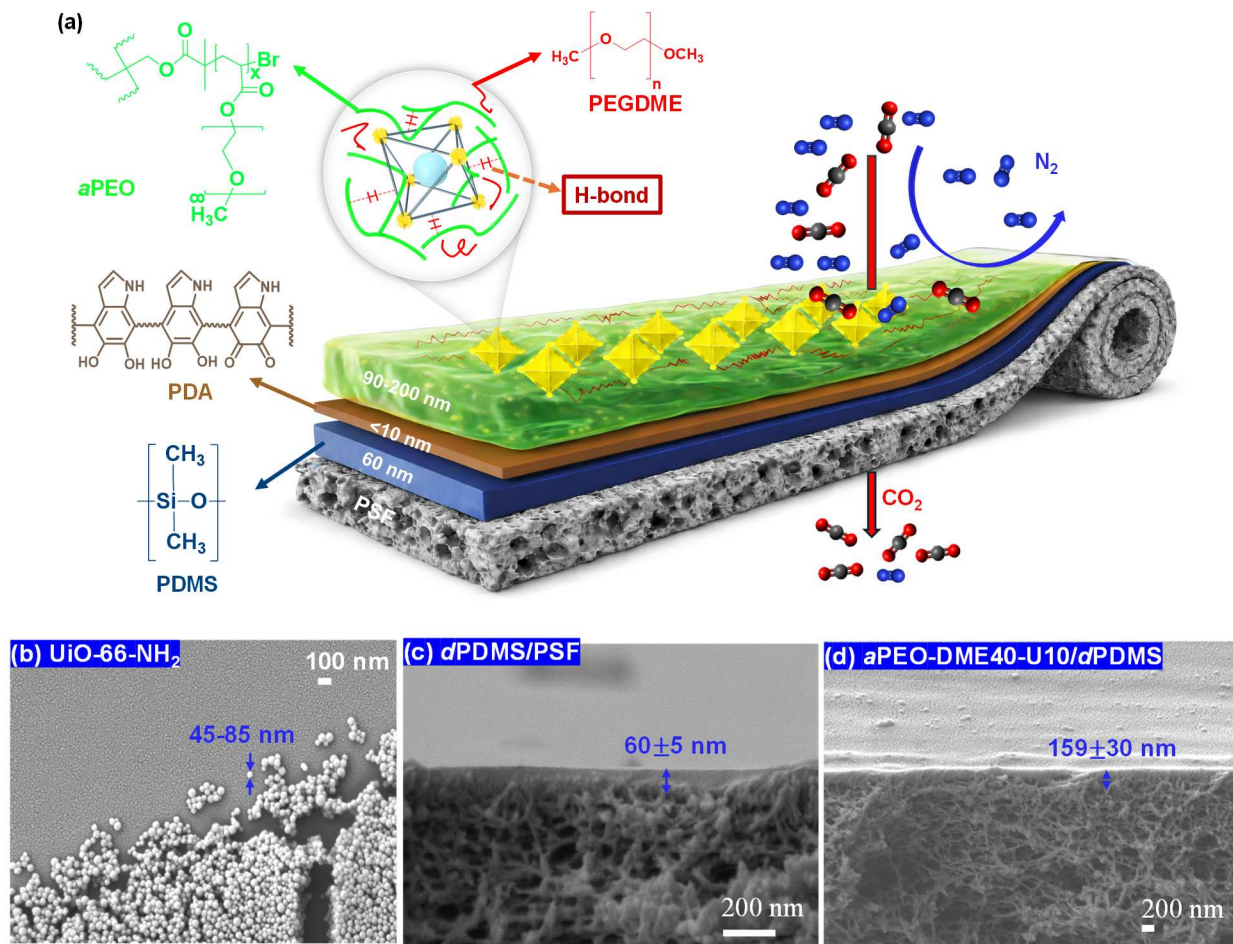


Figure 1. Developed *a*PEO-DMEx-Uy/*d*PDMS/PSF membranes, where the numbers of *x* and *y* represent the mass content of PEGDME and UiO-66-NH₂ NPs in the selective layers, respectively. (a) Schematic. SEM images of (b) UiO-66-NH₂ NPs, (c) *d*PDMS, and (d) *a*PEO-DME40-U10. The coating solutions contain 1.2 mass% polymers and UiO-66-NH₂.

Fig. 1b shows SEM images of UiO-66-NH₂ NPs with 45 – 84 nm. PDMS is used as the gutter layer due to its exceptionally high CO₂ permeance (9000 GPU), and its surface is modified with PDA to improve adhesion with *a*PEO [8, 9]. The *d*PDMS layer exhibits a thickness of 60 nm (Fig. 1c). For *a*PEO-DMEx-Uy membranes, there is no clear contrast between the gutter and selective layers, and their total thickness is 159 nm, yielding an estimated selective layer thickness of 99 nm. The presence of NPs in the SEM images confirms that they are well distributed throughout the polymer matrix (Fig. 1d).

The NFN membranes were also produced using a lab-scale roll-to-roll coating apparatus at Membrane Technology and Research, Inc. (MTR) [10], yielding an industrial membrane with a width of 12 inches and any desirable lengths.

Membrane testing protocols

University at Buffalo, State University of New York (UB) built a bench-scale test skid (Fig. 2) for the field test at NCCC. It has two mass flow controllers (MFC) to provide feed flow and sweep gas at desirable flow rates. No temperature control was used, and thus, the membrane test was conducted at room temperature (21 °C).

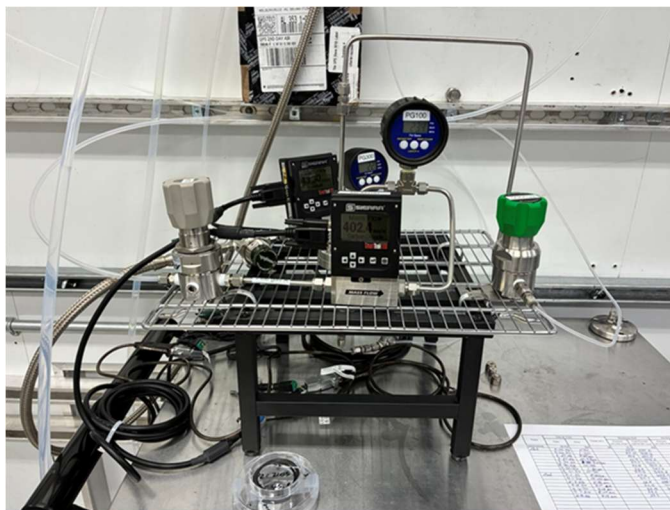


Figure 2. UB's test skid at NCCC for the field test.

Membranes were challenged with real flue gas using a constant-pressure and variable-volume system housed in the Lab-Scale Test Unit at NCCC. During the 610-h field test campaign from March 20th to April 26th, 2026, NCCC provided natural gas-derived flue gas from a package boiler at 400 cm³(STP)/min (sccm). Helium was used as a sweep gas on the permeate at 43 sccm and ~1.6 psig. All streams were analyzed using gas chromatography, and the stage-cut (defined as the fraction of the feed gas entering the permeate side) is less than 0.2%.

The MTR-fabricated membrane was evaluated using real flue gas derived from a natural gas-fired boiler at NCCC. The feed gas initially contained 8.03 mol% CO₂, 84.84 mol% N₂, and 7.13 mol% O₂, and then at 420th h, the composition changed to 4.02 mol% CO₂, 82.73 mol% N₂, and 13.65 mol% O₂ (Fig. 3). The flue gas also contained 1000 ppm H₂O and 10-15 ppm NO_x.

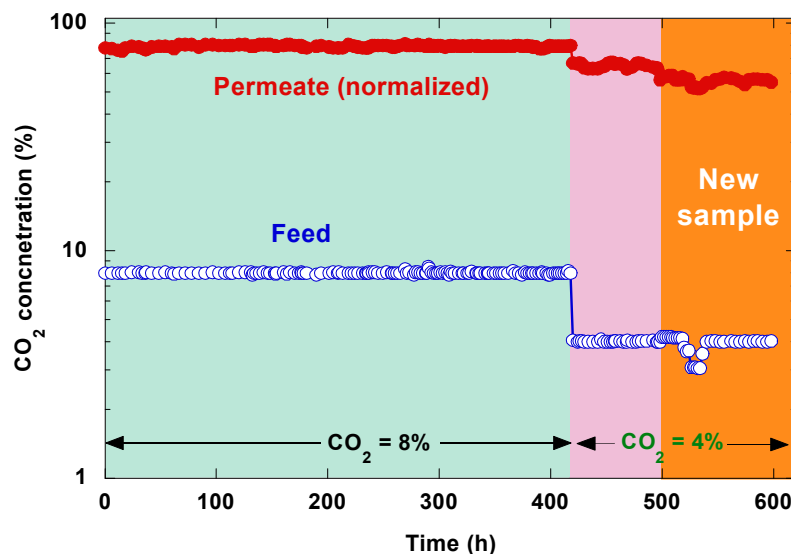


Figure 3. CO₂ concentrations of feed and permeate during the field test.

Figures 4 and 5 show the gas permeance and selectivity collected continuously for over 4 weeks at 22 psig and 21 °C, respectively. The membrane initially showed mixed-gas CO₂ permeance of 1100 GPU, CO₂/N₂ selectivity of 55, and CO₂/O₂ selectivity of 17, which are lower than pure-gas properties (CO₂ permeance of 2100 GPU and CO₂/N₂ selectivity of 52 at 23 °C), likely due to concentration polarization on both the feed and permeate side of the membrane, as well as feed compression effect. When the flue gas was switched to lower CO₂ content (4.02%), mixed-gas CO₂ permeance increased to 1400 GPU, while CO₂/N₂ and CO₂/O₂ selectivity remained unchanged. Overall, the MTR membrane demonstrates stable separation properties over time.

We also started testing a second membrane fabricated using a batch dip-coater at 490th h. The membrane showed mixed-gas CO₂ permeance of 2200 GPU, CO₂/N₂ selectivity of 42, and CO₂/O₂ selectivity of 14, while the CO₂ permeance is lower than the pure-gas one at 23 °C (3700 GPU), but the mixed-gas CO₂/N₂ selectivity is similar to the pure-gas one at 23 °C (44). The membrane shows stable separation properties during the 120-h test.

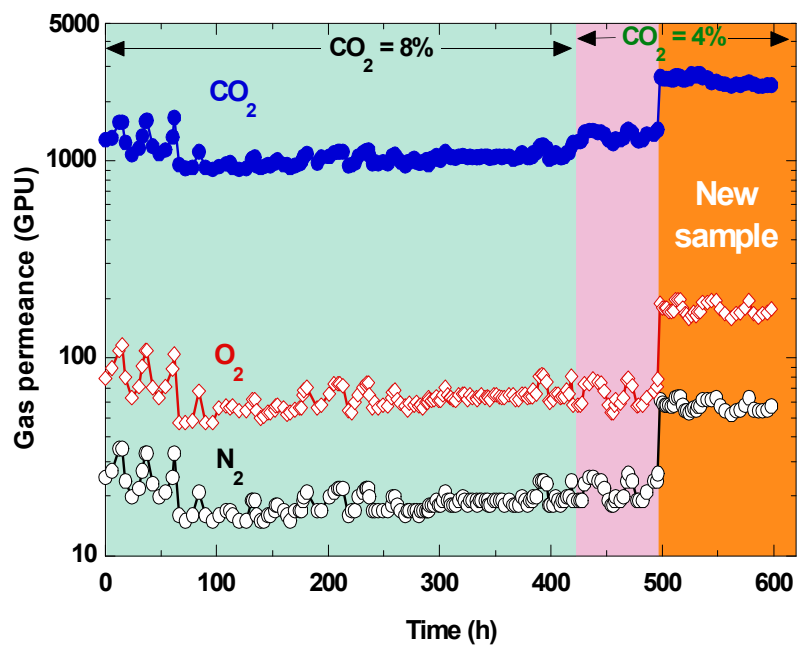


Figure 4. Gas permeance of long-term stability test at NCCC.

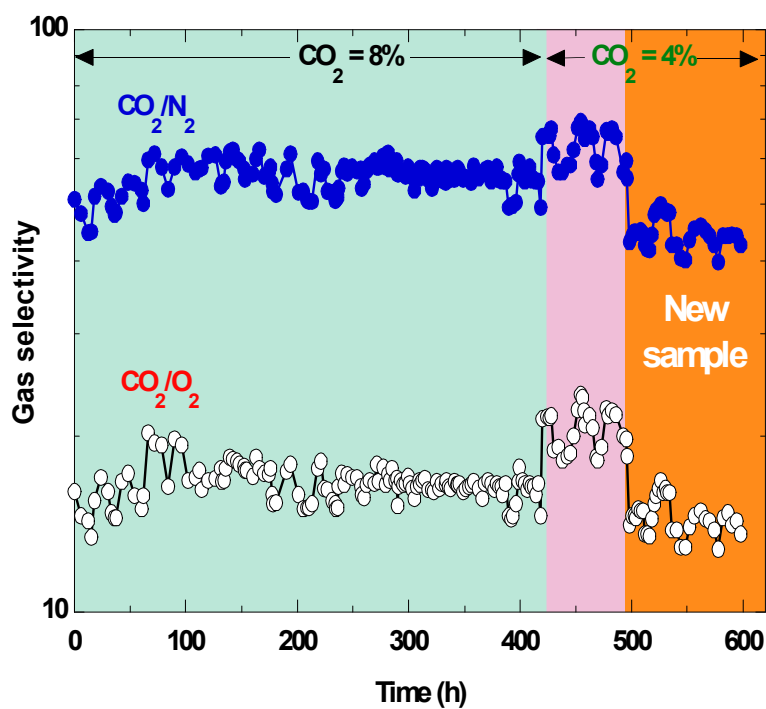


Figure 5. Gas selectivity of long-term stability test at NCCC.

Conclusions

Two membrane coupons were challenged with real flue gas at NCCC, and both exhibited stable CO₂ permeance and CO₂/N₂ selectivity over 610 hours. Interestingly, the membranes show lower mixed-gas CO₂ permeance than the pure-gas one, but similar CO₂/N₂ selectivity. The membranes exhibit among the best separation properties reported in the literature (mixed-gas CO₂ permeance of 2200 GPU and a CO₂/N₂ selectivity of 42, with a feed gas containing 4% CO₂). Future work will focus on the scale-up production of the membranes and pilot-scale demonstration of membrane modules.

Acknowledgement

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