

Supplementary Information

for

Binary-filler engineering of ZIF-8 and mesoporous silica in PEBAX mixed-matrix membranes toward enhanced CO₂ separation performance

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Supplementary Figures

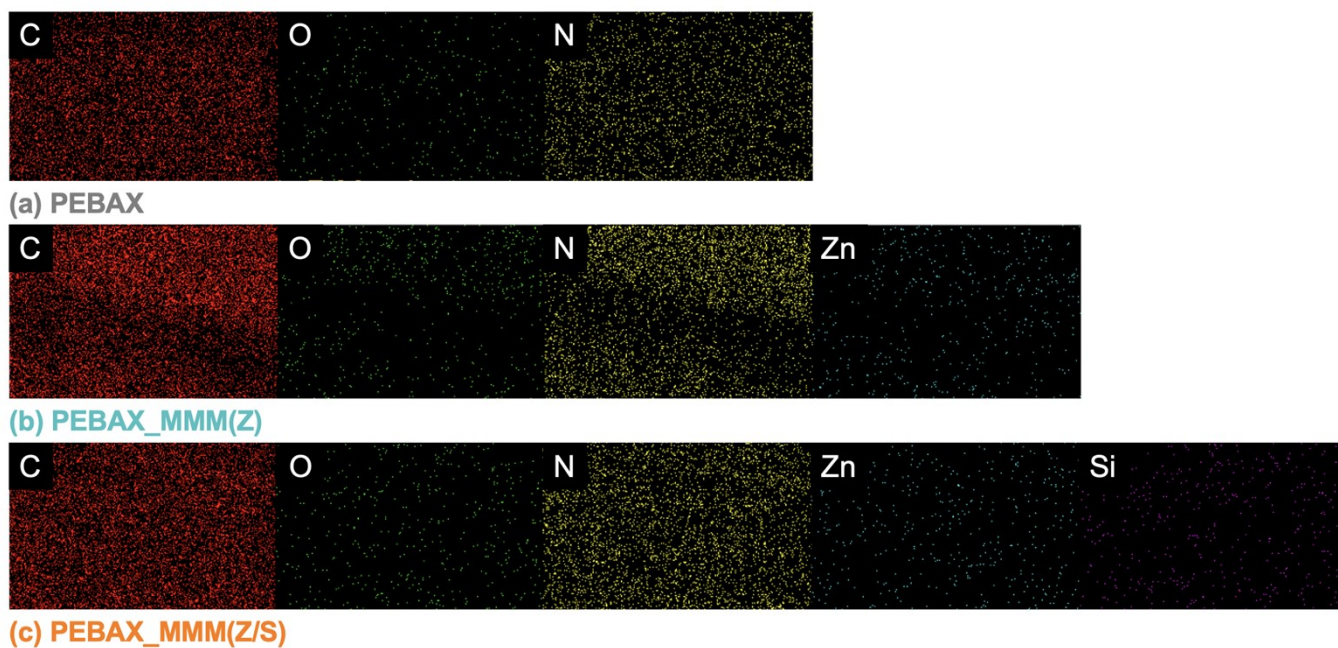


Fig. S1 EDS elemental mapping images of (a) pristine PEBAX, (b) PEBAX_MMM(Z), and (c) PEBAX_MMM(Z/S) membranes showing the distribution of C, O, N, Zn, and Si elements.

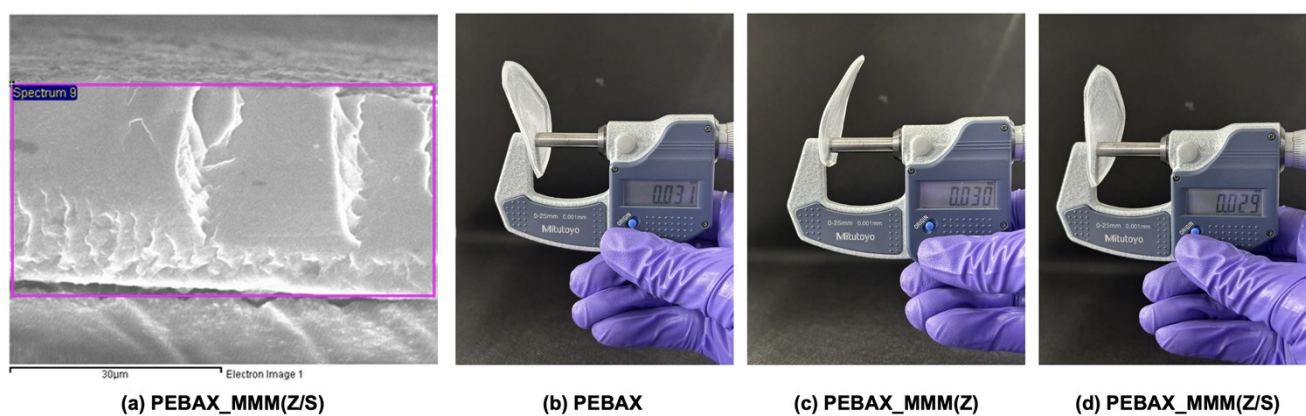


Fig. S2 Low-magnification cross-sectional SEM image of the PEBAX_MMM(Z/S) membrane (a) and thickness measurements of (b) pristine PEBAX, (c) PEBAX_MMM(Z), and (d) PEBAX_MMM(Z/S) membranes, showing comparable membrane thicknesses of approximately $30 \pm 1 \mu\text{m}$.

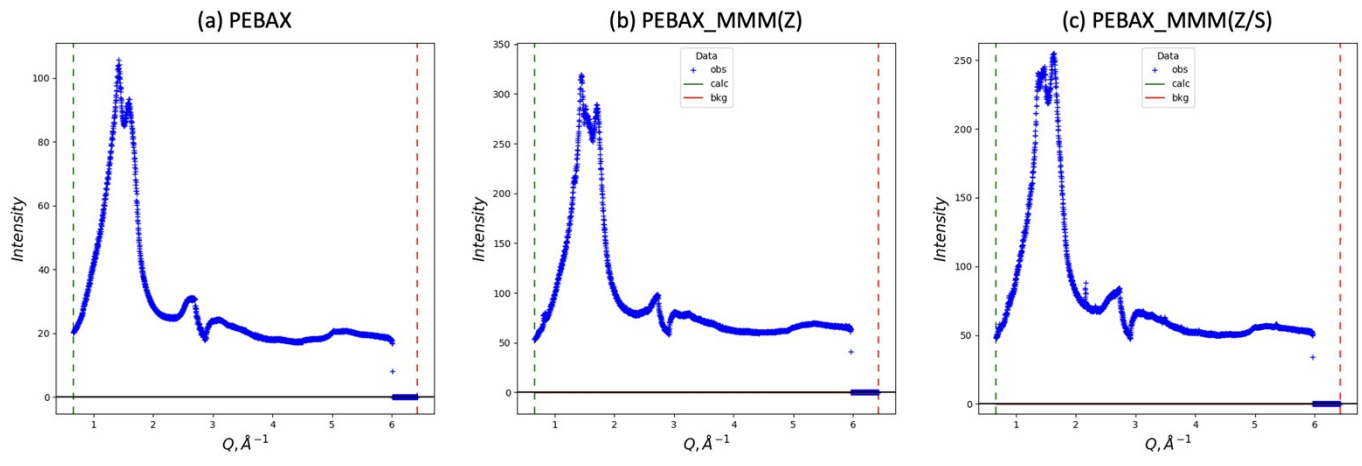


Fig. S3 Azimuthally integrated 1D GIWAXS profiles derived from the 2D GIWAXS patterns of (a) pristine PEBAX, (b) PEBAX_MMM(Z), and (c) PEBAX_MMM(Z/S) membranes.

Supplementary Tables

Table S1. Gas separation performance of PEBAX_MMM(Z) membrane (CO₂/N₂ feed ratio 50:50).

PEBAX_MMM(Z)	Gas	Temperature	Total press.	Partial press.	Permeance	Permeability	Selectivity
<i>feed gas ratio (%)</i>	<i>[-]</i>	<i>[K]</i>	<i>[bar]</i>	<i>[bar]</i>	<i>[mol/s/m²/Pa]</i>	<i>[Barrer]</i>	<i>[-]</i>
50	CO ₂	291	2.01	1.005	1.77×10^{-9}	217.74	31.0
50	N ₂			1.005	5.72×10^{-11}	7.03	

Preliminary mixed-gas permeation performance of PEBAX_MMM(Z) membrane under a CO₂/N₂ feed ratio of 50:50. Data represent a single measurement under dry-feed conditions (2.01 bar total pressure, 291 K). The reported values are preliminary and require systematic replicate measurements and humidified-feed evaluation to confirm the mixed-gas separation behavior, which will be reported in a dedicated follow-up study.

Table S2. Gas separation performance of PEBAX_MMM(Z/S) membrane (CO₂/N₂ feed ratio 50:50).

PEBAX_MMM(Z/S)	Gas	Temperature	Total press.	Partial press.	Permeance	Permeability	Selectivity
<i>feed gas ratio (%)</i>	<i>[-]</i>	<i>[K]</i>	<i>[bar]</i>	<i>[bar]</i>	<i>[mol/s/m²/Pa]</i>	<i>[Barrer]</i>	<i>[-]</i>
50	CO ₂	291	2.01	1.005	5.01×10^{-10}	51.08	10.8
50	N ₂			1.005	4.65×10^{-11}	4.74	

Preliminary mixed-gas permeation performance of PEBAX_MMM(Z/S) membrane under a CO₂/N₂ feed ratio of 50:50. Data represent a single measurement under dry-feed conditions (2.01 bar total pressure, 291 K). The reported values are preliminary and require systematic replicate measurements and humidified-feed evaluation to confirm the mixed-gas separation behavior, which will be reported in a dedicated follow-up study.