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APPENDICES

Appendix A The Experimental Flow Rate of Methane (CH_4), Carbon Dioxide (CO_2), and Nitrogen (N_2) of Dense Membrane and Mixed Matrix Membranes in Performance at 50 psi and 100 psi

Table A1 Pure Ultem membrane

Gas	Pressure (psi)	Flow rate (cm^3/s)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permance
N_2	50	1.81E-05	0.00199	0.00199	2.88E-07
		1.81E-05	0.00199		
		1.81E-05	0.00199		
	100	3.66E-05	0.00201	0.00201	3.40E-07
		3.66E-05	0.00201		
		3.66E-05	0.00201		
CH_4	50	6.79E-06	0.00074	0.00074	4.05E-08
		6.79E-06	0.00074		
		6.79E-06	0.00075		
	100	1.36E-05	0.00075	0.00075	4.67E-08
		1.36E-05	0.00074		
		1.36E-05	0.00075		
N_2	100	3.66E-05	0.00201	0.00201	1.22E-06
		3.66E-05	0.00201		
		3.66E-05	0.00201		
CO_2	50	1.88E-04	0.02067	0.02065	1.80E-05
		1.88E-04	0.02064		
		1.88E-04	0.02064		
	100	3.76E-04	0.02062	0.02063	1.79E-05
		3.76E-04	0.02062		
		3.77E-04	0.02066		
N_2	100	3.66E-05	0.00201	0.00201	8.99E-07
		3.66E-05	0.00201		
		3.66E-05	0.00201		

Table A2 10 wt% MOF-199 MMMs

Gas	Pressure (psi)	Flow rate (cm^3/s)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permance
N_2	50	2.41E-05	0.00264	0.00264	5.87E-07
		2.41E-05	0.00264		
		2.41E-05	0.00264		
	100	5.83E-05	0.00320	0.00266	4.65E-04
		4.36E-05	0.00239		
		4.36E-05	0.00239		
CH_4	50	1.03E-05	0.00113	0.00112	9.23E-08
		1.03E-05	0.00112		
		1.03E-05	0.00112		
	100	2.05E-05	0.00113	0.00113	2.82E-07
		2.05E-05	0.00113		
		2.05E-05	0.00113		
N_2	100	5.84E-05	0.00320	0.00266	4.66E-04
		4.36E-05	0.00239		
		4.36E-05	0.00239		
CO_2	50	3.76E-04	0.04125	0.04125	6.20E-05
		3.75E-04	0.04119		
		3.77E-04	0.04131		
	100	7.46E-04	0.04094	0.04082	2.10E-04
		7.40E-04	0.04058		
		7.46E-04	0.04094		
N_2	100	5.82E-05	0.00319	0.00266	4.63E-04
		4.36E-05	0.00239		
		4.36E-05	0.00239		

Table A3 20 wt% MOF-199 MMMs

Gas	Pressure (psi)	Flow rate (cm^3/s)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permance
N_2	50	2.53E-05	0.00278	0.00271	5.57E-05
		2.44E-05	0.00268		
		2.44E-05	0.00268		
	100	5.13E-05	0.00282	0.00273	1.46E-04
		5.13E-05	0.00282		
		4.67E-05	0.00256		
CH_4	50	1.14E-05	0.00125	0.00124	3.75E-06
		1.13E-05	0.00124		
		1.13E-05	0.00124		
	100	2.27E-05	0.00125	0.00125	2.62E-07
		2.27E-05	0.00125		
		2.27E-05	0.00125		
N_2	100	5.13E-05	0.00281	0.00273	1.47E-04
		5.13E-05	0.00281		
		4.67E-05	0.00256		
CO_2	50	4.56E-04	0.05006	0.05021	1.92E-04
		4.57E-04	0.05015		
		4.60E-04	0.05042		
	100	9.09E-04	0.04987	0.04994	2.78E-04
		9.06E-04	0.04969		
		9.16E-04	0.05024		
N_2	100	5.13E-05	0.00282	0.00273	1.46E-04
		5.13E-05	0.00281		
		4.67E-05	0.00256		

Table A4 30 wt% MOF-199 MMMs

Gas	Pressure (psi)	Flow rate (cm^3/s)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permance
N_2	50	2.79E-05	0.00306	0.00306	6.82E-07
		2.79E-05	0.00306		
		2.79E-05	0.00306		
	100	6.29E-05	0.00345	0.00308	3.27E-04
		5.33E-05	0.00293		
		5.20E-05	0.00285		
CH_4	50	1.24E-05	0.00136	0.00136	2.72E-07
		1.24E-05	0.00137		
		1.24E-05	0.00136		
	100	2.49E-05	0.00136	0.00137	4.15E-07
		2.49E-05	0.00136		
		2.49E-05	0.00137		
N_2	100	4.95E-05	0.00271	0.00272	2.15E-06
		4.95E-05	0.00272		
		4.96E-05	0.00272		
CO_2	50	5.34E-04	0.05861	0.05857	7.22E-05
		5.33E-04	0.05849		
		5.34E-04	0.05861		
	100	1.06E-03	0.05812	0.05771	3.72E-04
		1.05E-03	0.05739		
		1.05E-03	0.05763		
N_2	100	4.96E-05	0.00272	0.00272	1.64E-06
		4.95E-05	0.00272		
		4.95E-05	0.00272		

Table A5 10 wt% ZIF-8 MMMs

Gas	Pressure (psi)	Flow rate (cm^3/s)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permance
N_2	50	2.98E-05	0.00327	0.00327	3.25E-06
		2.98E-05	0.00327		
		2.98E-05	0.00327		
	100	6.01E-05	0.00330	0.00329	2.74E-06
		6.00E-05	0.00329		
		6.00E-05	0.00329		
CH_4	50	1.15E-05	0.00127	0.00126	2.94E-07
		1.15E-05	0.00126		
		1.15E-05	0.00127		
	100	2.32E-05	0.00127	0.00127	8.08E-06
		2.29E-05	0.00126		
		2.32E-05	0.00127		
N_2	100	6.00E-05	0.00329	0.00329	2.41E-06
		6.00E-05	0.00329		
		6.00E-05	0.00329		
CO_2	50	3.35E-04	0.03677	0.03674	2.84E-05
		3.35E-04	0.03672		
		3.35E-04	0.03672		
	100	6.56E-04	0.03600	0.03581	1.87E-04
		6.53E-04	0.03581		
		6.49E-04	0.03562		
N_2	100	6.00E-05	0.00329	0.00329	3.97E-06
		6.00E-05	0.00329		
		5.99E-05	0.00328		

Table A6 20 wt% ZIF-8 MMMs

Gas	Pressure (psi)	Flow rate (cm^3/s)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permance
N_2	50	3.60E-05	0.00395	0.00395	4.73E-06
		3.60E-05	0.00395		
		3.59E-05	0.00394		
	100	7.27E-05	0.00399	0.00398	4.81E-06
		7.25E-05	0.00398		
		7.25E-05	0.00398		
CH_4	50	1.48E-05	0.00163	0.00162	4.84E-07
		1.48E-05	0.00162		
		1.48E-05	0.00162		
	100	2.95E-05	0.00162	0.00162	1.52E-06
		2.94E-05	0.00162		
		2.94E-05	0.00161		
N_2	100	7.24E-05	0.00397	0.00398	8.11E-06
		7.25E-05	0.00398		
		7.27E-05	0.00399		
CO_2	50	4.58E-04	0.05024	0.05018	5.30E-05
		4.57E-04	0.05015		
		4.57E-04	0.05015		
	100	8.90E-04	0.04881	0.04847	3.43E-04
		8.83E-04	0.04846		
		8.77E-04	0.04812		
N_2	100	7.27E-05	0.00399	0.00398	1.06E-05
		7.24E-05	0.00397		
		7.23E-05	0.00397		

Appendix B The Experimental Gas Selectivity of Dense Membrane and Mixed Matrix Membranes in Performance at 50 psi and 100 psi

Table B1 Gas selectivity determined from gas permeance of Ultem membrane and MOF-MMMs at pressures of 50 psi and 100 psi

Membrane	MOF Loading (wt%)	CO_2/CH_4 Selectivity		CO_2/N_2 Selectivity	
		50 psi	100 psi	50 psi	100 psi
Pure Ultem	0	27.719	27.696	10.396	10.266
MOF-199 MMMs	10	36.394	36.104	15.867	15.614
	20	40.361	40.025	18.501	18.280
	30	42.910	42.276	19.145	18.758
ZIF-8 MMMs	10	29.042	28.261	11.232	10.872
	20	30.887	30.008	12.707	12.172

Appendix C The Gas Permeance Predicted by Maxwell Model for MOF-MMMs at Pressure of 50 psi

Table C1 Comparison of gas permeances for MOF-MMMs at pressure of 50 psi based on Mexwell model and experimental data.

MOFs	Gas	Loading		P_c (GPU)	P_d (GPU)	P_{eff}	
		wt. fraction	vol. fraction			Maxwell's model	Experiment
MOF-199	CO_2	10	0.168	0.02065	44	0.03314	0.04240
		20	0.312	0.02065	44	0.04869	0.05021
		30	0.437	0.02065	44	0.06862	0.05857
	CH_4	10	0.168	0.00074	15	0.00119	0.00116
		20	0.312	0.00074	15	0.00175	0.05802
		30	0.437	0.00074	15	0.00246	0.06583
	N_2	10	0.168	0.00199	19	0.00320	0.00267
		20	0.312	0.00199	19	0.00470	0.00271
		30	0.437	0.00199	19	0.00662	0.07364
ZIF-8	CO_2	10	0.168	0.02065	44	0.03314	0.08145
		20	0.312	0.02065	44	0.04869	0.05018
		30	0.437	0.02065	44	-	-
	CH_4	10	0.168	0.00074	15	0.00119	0.08926
		20	0.312	0.00074	15	0.00175	0.09707
		30	0.437	0.00074	15	-	-
	N_2	10	0.168	0.00199	19	0.00320	0.00327
		20	0.312	0.00199	19	0.00470	0.00395
		30	0.437	0.00199	19	-	-

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1. Ketsuwan, T.; Rirksomboon, T.; Kulprathipanja, S.; and Bowen, T.C. (2014, April 22) Solid-Polymer Mixed Matrix Membranes for CO_2/CH_4 Separation: Metal Organic Frameworks and Polyetherimide. Paper presented at The 5th Research Symposium on Petrochemical and Materials Technology and The 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.
2. Ketsuwan, T.; Rirksomboon, T.; Kulprathipanja, S.; and Bowen, T.C. (2014, May 7-8) Enhanced Selectivity of Metal Organic Frameworks-Polyetherimide Mixed Matrix Membranes for CO_2/CH_4 Separation. Paper presented at ICERE: International Conference on Environment and Renewable Energy, Paris, France.