REFERENCES

Bos, A., Punt, I.G.M., Wessling, M., and Strathmann, H. (1998). Plasticization-resistance glassy polyimide membranes for CO_2/CO_4 separations. Separation and Purification Technology, 14, 27-39.

Chung, T.S. (2007). Mixed matrix membranes (MMMs) comprising organic polymers with dispersed inorganic fillers for gas separation. Progress in Polymer Science, 32, 483-507.

Charoenphol, J. (2004). Mixed matrix membranes for CO_2/N_2 separation. The Petroleum and Petrochemical College, Chulalongkorn University.

Kulprathipanja, S., (2002). Mixed matrix membrane development. *Membrane Technology* (*Volume* 2002, *Issue* 4, *pp*. 9-12).

Pechar, T.W., Kim, S., Vaughan, B., Marand, E., and Davis, R. (2002). Preparation and characterization of glassy fluorinated polyimide zeolite-mixed matrix membranes. Desalination, 146, 3-9.

Pechar, T.W., Kim, S., Vaughan, B., and Marand, E. (2006). Fabrication and characterization of polyimide-zeolite L mixed matrix membranes for gas separation. Journal of Membrane Science, 277, 195-202.

Shao, L., Chung, T.S., Goh, S.H., and Pramoda, K.P. (2006). Polyimide modification by a linear aliphatic diamine to enhance transport performance and plasticization resistance. Journal of Membrane Science, 256, 46-56.

Srisilp, A. (2004). Zeolite-polyimide mixed matrix membranes for olefin/paraffin separation. The Petroleum and Petrochemical College, Chulalongkorn University.

Tanupabrungsun, T. (2006). Mixed matrix membrane for gas separation. The Petroleum and Petrochemical College, Chulalongkorn University.

Vijitunya, P. (2001). Dispersed liquid-polymer mixed mixed matrix membrane for olefin/paraffin separation. The Petroleum and Petrochemical College, Chulalongkorn University.

Anson, M., Marchese, J., Garis, E., Ochoa, N., and Pagliero, C. (2004). ABS copolymer-activated carbon mixed matrix membranes for CO_2/CH_4 separation. Journal of Membrane Science, 243, 19-28.

Baker, R.W. (2002). Future directions of membrane gas separation technology. Industrial Engineering Chemical Research, 41, 1393-1411.

Ettouney, H. and Majeed, U. (1997). Permeability functions for pure and mixture gases in silicone rubber and polysulfone membranes:Dependence on pressure and composition. Journal of Membrane Science, 135, 251-261.

Freni, S., Cavallaro, S., Donato, S., Chiodo, V., and Vita, A. (2004). Experimental evaluation on the CO_2 separation process supported by polymeric membranes. Materials Letters, 58, 1865-1872.

Hibshman, C., Mager, M., and Marand, E. (2004). Effects of feed pressure on fluorinated polyimide-organosilicate hybrid membranes. Journal of Membrane Science, 229, 73-80.

Hu, C.C., Liu, T.C., Lee, K.R., and Ruaan, R.C. (2006). Zeolite-filled PMMA composite membranes: influence of coupling agent addition on gas separation properties. Desalination, 193, 14-24.

Ismail, A.F., and Lorna, W. (2002). Penetrant-induced plasticization phenomenon in glassy polymers for gas separation membrane. Separation and Purification Technology, 27, 173-194.

Ismail, A.F., and Lorna, W. (2003). Suppression of plasticization in polysulfone membranes for gas separations by heat-treatment technique. Separation and Purification Technology, 30, 37-46.

Kesting, R.E., and Fritzsche, A.K. (1995). Polymeric Gas Separation Membranes. New York: John Wiley & Sons, Inc.

Krol, J.J., Boerrigter, M., and Koops, G.H. (2001). Polyimide hollow fiber gas separation membranes: preparation and the suppression of plasticization in propane/propylene environments. Journal of Membrane Science, 184, 275-286.

Norman, N. L., Antony, G. F., W.S. Winston, H., Takeshi, M. (2008). Advanced Membrane Technology and Applications. New Jersey: John Wiley & Sons, Inc.

APPENDICES

Appendix A The Calculation of Gas Permeation Rate

The permeance or pressure normalized flux of component 'i' is expressed as a thickness normalized permeation rate, $\left(\frac{P}{\delta}\right)_i$. Permeances are expressed in gas permeation units, GPU, where GPU = $1*10^{-6}$ $cm^3(STP)/cm^2.sec.cmHg$.

$$\left(\frac{P}{\delta}\right)_i = \frac{Q_i \times 14.7 \times 10^6}{(A) \times (\Delta P) \times 76}$$

Where

$\left(\frac{P}{\delta}\right)_i$ = permeance of gas 'i' (GPU)

P = permeability of gas 'i' ($cm^3(STP).cm/cm^2.sec.cmHg$)

δ = thickness of membrane (cm)

Q_i = volumetric flow rate of gas 'i' (cm^3/sec)

A = area of membrane (cm^2)

ΔP = pressure different across membrane (psi)

Appendix B The experimental flow rate of methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2) and hydrogen (H_2) of dense membrane and mixed matrix membranes in performance at pressure of 100 psi.

Table B1 Pure Ultem membrane

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	386.3	23178	1.08E-05	0.0004	0.00039	0.0000
			382.05	22923	1.09E-05	0.0004		
			395.1	23706	1.05E-05	0.0004		
CH_4	100	0.25	1620	97200	2.57E-06	0.0001	0.00009	0.0000
			1600	96000	2.60E-06	0.0001		
			1590	95400	2.62E-06	0.0001		
H_2	100	0.25	17.3	1038	2.41E-04	0.0087	0.00900	0.0003
			16.25	975	2.56E-04	0.0093		
			16.83	1009.8	2.48E-04	0.0090		
CO_2	100	0.25	58.5	3510	7.12E-05	0.0026	0.00255	0.0000
			60.2	3612	6.92E-05	0.0025		
			59.2	3552	7.04E-05	0.0026		

Table B2 20% AC/MMMs

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	159.7	9582	2.61E-05	0.0009	0.00094	0.0000
			160	9600	2.60E-05	0.0009		
			164.25	9855	2.54E-05	0.0009		
CH_4	100	0.25	704.5	42270	5.91E-06	0.0002	0.00021	0.0000
			711.2	42672	5.86E-06	0.0002		
			723.1	43386	5.76E-06	0.0002		
H_2	100	0.25	5.2	312	8.01E-04	0.0290	0.03003	0.0009
			5	300	8.33E-04	0.0302		
			4.9	294	8.50E-04	0.0308		
CO_2	100	0.25	18.1	1086	2.30E-04	0.0083	0.00833	0.0000
			18.1	1086	2.30E-04	0.0083		
			18.2	1092	2.29E-04	0.0083		

Table B3 PEG/AC MMMs

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	349.1	20946	1.19E-05	0.0004	0.00043	0.0000
			351	21060	1.19E-05	0.0004		
			352.4	21144	1.18E-05	0.0004		
CH_4	100	0.25	1514	90840	2.75E-06	0.0001	0.00010	0.0000
			1509	90540	2.76E-06	0.0001		
			1523	91380	2.74E-06	0.0001		
H_2	100	0.25	14.5	870	2.87E-04	0.0104	0.01012	0.0003
			15.1	906	2.76E-04	0.0100		
			15.2	912	2.74E-04	0.0099		
CO_2	100	0.25	31.2	1872	1.34E-04	0.0048	0.00507	0.0003
			30	1800	1.39E-04	0.0050		
			28.3	1698	1.47E-04	0.0053		

Table B4 1,2-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	253	15180	1.65E-05	0.0006	0.00060	0.0000
			250.2	15012	1.67E-05	0.0006		
			257.1	15426	1.62E-05	0.0006		
CH_4	100	0.25	952	57120	4.38E-06	0.0002	0.00016	0.0000
			957	57420	4.35E-06	0.0002		
			960	57600	4.34E-06	0.0002		
H_2	100	0.25	8.9	534	4.68E-04	0.0170	0.01717	0.0002
			8.7	522	4.79E-04	0.0174		
			8.8	528	4.73E-04	0.0172		
CO_2	100	0.25	20.4	1224	2.04E-04	0.0074	0.00744	0.0000
			20.3	1218	2.05E-04	0.0074		
			20.2	1212	2.06E-04	0.0075		

Table B5 1,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	323	19380	1.29E-05	0.0005	0.00047	0.0000
			321	19260	1.30E-05	0.0005		
			320	19200	1.30E-05	0.0005		
CH_4	100	0.25	1182	70920	3.53E-06	0.0001	0.00013	0.0000
			1180	70800	3.53E-06	0.0001		
			1176	70560	3.54E-06	0.0001		
H_2	100	0.25	12.2	732	3.42E-04	0.0124	0.01252	0.0002
			12.1	726	3.44E-04	0.0125		
			11.9	714	3.50E-04	0.0127		
CO_2	100	0.25	28.2	1692	1.48E-04	0.0054	0.00543	0.0001
			27.3	1638	1.53E-04	0.0055		
			28	1680	1.49E-04	0.0054		

Table B6 1,4-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	289.5	17370	1.44E-05	0.0005	0.00052	0.0000
			293	17580	1.42E-05	0.0005		
			295	17700	1.41E-05	0.0005		
CH_4	100	0.25	1050	63000	3.97E-06	0.0001	0.00014	0.0000
			1050	63000	3.97E-06	0.0001		
			1050	63000	3.97E-06	0.0001		
H_2	100	0.25	9.1	546	4.58E-04	0.0166	0.01587	0.0007
			9.5	570	4.39E-04	0.0159		
			10	600	4.17E-04	0.0151		
CO_2	100	0.25	24.2	1452	1.72E-04	0.0062	0.00630	0.0001
			24.4	1464	1.71E-04	0.0062		
			23.4	1404	1.78E-04	0.0065		

Table B7 2,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time		Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
			Min	(sec)				
N_2	100	0.25	221	13260	1.89E-05	0.0007	0.00068	0.0000
			227.3	13638	1.83E-05	0.0007		
			217	13020	1.92E-05	0.0007		
CH_4	100	0.25	890.3	53418	4.68E-06	0.0002	0.00017	0.0000
			882	52920	4.72E-06	0.0002		
			900	54000	4.63E-06	0.0002		
H_2	100	0.25	7.52	451.2	5.54E-04	0.0201	0.02016	0.0002
			7.54	452.4	5.53E-04	0.0200		
			7.42	445.2	5.62E-04	0.0204		
CO_2	100	0.25	19.1	1146	2.18E-04	0.0079	0.00796	0.0001
			18.7	1122	2.23E-04	0.0081		
			19.1	1146	2.18E-04	0.0079		

Table B8 Selectivity at 100 psia of MMMs

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
Ultem	27.04	0.0005	23.10	6.54
AC	39.31	0.0011	32.06	8.89
PEG/AC	50.87	0.0005	23.50	11.78
1,2AC	47.11	0.0008	28.80	12.48
1,3AC	42.38	0.0006	26.63	11.55
1,4AC	43.76	0.0007	30.73	12.19
2,3AC	46.97	0.0009	29.59	11.69

Appendix C The experimental flow rate of methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2) and hydrogen (H_2) of asymmetric membrane and mixed matrix membranes in performance at pressure of 50 and 100 psi and 10% liquid loading (only butanediol isomers).

Table C1 Pure Ultem membrane

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	492.6	5.08E-04	0.0445	0.044	0.0001
			493.2	5.07E-04	0.0444		
			491.3	5.09E-04	0.0446		
			492.2	5.08E-04	0.0445		
	100	0.25	201	1.24E-03	0.0451	0.045	0.0001
			202.2	1.24E-03	0.0448		
			202.4	1.24E-03	0.0448		
			201.5	1.24E-03	0.0450		
H2	50	0.25	16.1	1.55E-02	1.3602	1.376	0.0270
			16.2	1.54E-02	1.3518		
			15.5	1.61E-02	1.4129		
			15.9	1.57E-02	1.3774		
	100	0.25	6.4	3.91E-02	1.4161	1.397	0.0183
			6.6	3.79E-02	1.3732		
			6.45	3.88E-02	1.4051		
			6.5	3.85E-02	1.3943		
	50	0.25	683	3.66E-04	0.0321	0.032	0.0001
			682	3.67E-04	0.0321		
			681	3.67E-04	0.0322		
			684	3.65E-04	0.0320		
	100	0.25	282	8.87E-04	0.0321	0.032	0.0001
			284	8.80E-04	0.0319		
			281.5	8.88E-04	0.0322		
			281	8.90E-04	0.0323		
CO_2	50	0.25	22.2	1.13E-02	0.9865	0.986	0.0036
			22.1	1.13E-02	0.9909		
			22.2	1.13E-02	0.9865		
			22.3	1.12E-02	0.9821		
	100	0.25	9.6	2.60E-02	0.9441	0.959	0.0178
			9.2	2.72E-02	0.9851		
			9.5	2.63E-02	0.9540		
			9.5	2.63E-02	0.9540		

Table C2 20% AC/MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	150.5	1.66E-03	0.1455	0.146	0.0006
			150	1.67E-03	0.1460		
			149.5	1.67E-03	0.1465		
			149	1.68E-03	0.1470		
	100	0.25	60.3	4.15E-03	0.1503	0.147	0.0055
			61	4.10E-03	0.1486		
			59.8	4.18E-03	0.1516		
			65	3.85E-03	0.1394		
H2	50	0.25	7.2	3.47E-02	3.0416	3.121	0.1232
			7.3	3.42E-02	3.0000		
			6.7	3.73E-02	3.2686		
			6.9	3.62E-02	3.1739		
	100	0.25	2.85	8.77E-02	3.1800	3.195	0.0658
			2.84	8.80E-02	3.1912		
			2.9	8.62E-02	3.1251		
			2.76	9.06E-02	3.2837		
CH_4	50	0.25	372	6.72E-04	0.0589	0.059	0.0001
			371	6.74E-04	0.0590		
			370.5	6.75E-04	0.0591		
			370	6.76E-04	0.0592		
	100	0.25	155	1.61E-03	0.0585	0.060	0.0008
			151	1.66E-03	0.0600		
			152	1.64E-03	0.0596		
			150.2	1.66E-03	0.0603		
CO_2	50	0.25	9.25	2.70E-02	2.3676	2.371	0.0162
			9.15	2.73E-02	2.3934		
			9.3	2.69E-02	2.3548		
			9.25	2.70E-02	2.3676		
	100	0.25	3.82	6.54E-02	2.3725	2.396	0.0395
			3.72	6.72E-02	2.4363		
			3.85	6.49E-02	2.3540		
			3.74	6.68E-02	2.4232		

Table C3 PEG/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	293	8.53E-04	0.0747	0.075	0.0016
			292	8.56E-04	0.0750		
			296	8.45E-04	0.0740		
			282	8.87E-04	0.0777		
	100	0.25	113	2.21E-03	0.0802	0.081	0.0006
			112	2.23E-03	0.0809		
			111.6	2.24E-03	0.0812		
			111.2	2.25E-03	0.0815		
H2	50	0.25	13.1	1.91E-02	1.6717	1.653	0.0214
			13.2	1.89E-02	1.6591		
			13.5	1.85E-02	1.6222		
			13.2	1.89E-02	1.6591		
	100	0.25	5.35	4.67E-02	1.6940	1.655	0.0576
			5.34	4.68E-02	1.6972		
			5.48	4.56E-02	1.6538		
			5.76	4.34E-02	1.5734		
CH_4	50	0.25	662	3.78E-04	0.0331	0.033	0.0002
			669	3.74E-04	0.0327		
			663	3.77E-04	0.0330		
			663	3.77E-04	0.0330		
	100	0.25	272	9.19E-04	0.0333	0.034	0.0002
			271	9.23E-04	0.0334		
			268	9.33E-04	0.0338		
			269	9.29E-04	0.0337		
CO_2	50	0.25	13.52	1.85E-02	1.6198	1.643	0.0311
			13.55	1.85E-02	1.6162		
			13.24	1.89E-02	1.6541		
			13.02	1.92E-02	1.6820		
	100	0.25	5.7	4.39E-02	1.5900	1.645	0.0443
			5.55	4.50E-02	1.6330		
			5.35	4.67E-02	1.6940		
			5.45	4.59E-02	1.6629		

Table C4 1,2-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	161	1.55E-03	0.1360	0.137	0.0024
			163	1.53E-03	0.1344		
			158	1.58E-03	0.1386		
			157	1.59E-03	0.1395		
	100	0.25	66	3.79E-03	0.1373	0.138	0.0027
			67	3.73E-03	0.1353		
			64	3.91E-03	0.1416		
			65	3.85E-03	0.1394		
H2	50	0.25	7.4	3.38E-02	2.9594	2.960	0.0327
			7.5	3.33E-02	2.9200		
			7.4	3.38E-02	2.9594		
			7.3	3.42E-02	3.0000		
	100	0.25	3.1	8.06E-02	2.9235	2.972	0.0563
			3.1	8.06E-02	2.9235		
			3	8.33E-02	3.0210		
			3	8.33E-02	3.0210		
CH_4	50	0.25	400	6.25E-04	0.0547	0.052	0.0025
			415	6.02E-04	0.0528		
			450	5.56E-04	0.0487		
			420	5.95E-04	0.0521		
	100	0.25	172	1.45E-03	0.0527	0.053	0.0009
			173	1.45E-03	0.0524		
			167	1.50E-03	0.0543		
			168	1.49E-03	0.0539		
CO_2	50	0.25	9.3	2.69E-02	2.3548	2.276	0.0596
			9.6	2.60E-02	2.2812		
			9.9	2.53E-02	2.2121		
			9.7	2.58E-02	2.2577		
	100	0.25	4	6.25E-02	2.2657	2.325	0.0487
			3.9	6.41E-02	2.3238		
			3.9	6.41E-02	2.3238		
			3.8	6.58E-02	2.3850		

Table C5 1,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	223	1.12E-03	0.0982	0.099	0.0004
			222	1.13E-03	0.0986		
			221	1.13E-03	0.0991		
			221	1.13E-03	0.0991		
	100	0.25	93	2.69E-03	0.0975	0.099	0.0014
			91	2.75E-03	0.0996		
			90	2.78E-03	0.1007		
			91	2.75E-03	0.0996		
H2	50	0.25	11	2.27E-02	1.9909	2.041	0.0995
			11	2.27E-02	1.9909		
			11	2.27E-02	1.9909		
			10	2.50E-02	2.1900		
	100	0.25	4.4	5.68E-02	2.0598	2.048	0.0229
			4.5	5.56E-02	2.0140		
			4.4	5.68E-02	2.0598		
			4.4	5.68E-02	2.0598		
CH_4	50	0.25	512	4.88E-04	0.0428	0.043	0.0001
			510	4.90E-04	0.0429		
			511	4.89E-04	0.0429		
			510	4.90E-04	0.0429		
	100	0.25	205	1.22E-03	0.0442	0.044	0.0007
			200	1.25E-03	0.0453		
			208	1.20E-03	0.0436		
			206	1.21E-03	0.0440		
CO_2	50	0.25	13.4	1.87E-02	1.6343	1.669	0.0351
			13.3	1.88E-02	1.6466		
			12.8	1.95E-02	1.7109		
			13	1.92E-02	1.6846		
	100	0.25	5.5	4.55E-02	1.6478	1.695	0.0563
			5.1	4.90E-02	1.7770		
			5.4	4.63E-02	1.6783		
			5.4	4.63E-02	1.6783		

Table C6 1,4-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	193	1.30E-03	0.1135	0.112	0.0009
			195	1.28E-03	0.1123		
			197	1.27E-03	0.1112		
			195	1.28E-03	0.1123		
	100	0.25	85	2.94E-03	0.1066	0.113	0.0047
			77	3.25E-03	0.1177		
			79	3.16E-03	0.1147		
			80	3.13E-03	0.1133		
H2	50	0.25	9.7	2.58E-02	2.2577	2.264	0.0118
			9.6	2.60E-02	2.2812		
			9.7	2.58E-02	2.2577		
			9.7	2.58E-02	2.2577		
	100	0.25	4.1	6.10E-02	2.2105	2.266	0.0463
			3.9	6.41E-02	2.3238		
			4	6.25E-02	2.2657		
			4	6.25E-02	2.2657		
CH_4	50	0.25	482	5.19E-04	0.0454	0.045	0.0003
			489	5.11E-04	0.0448		
			486	5.14E-04	0.0451		
			485	5.15E-04	0.0452		
	100	0.25	193	1.30E-03	0.0470	0.048	0.0006
			187	1.34E-03	0.0485		
			190	1.32E-03	0.0477		
			191	1.31E-03	0.0474		
CO_2	50	0.25	11.9	2.10E-02	1.8403	1.800	0.0559
			11.8	2.12E-02	1.8559		
			12.5	2.00E-02	1.7520		
			12.5	2.00E-02	1.7520		
	100	0.25	5.1	4.90E-02	1.7770	1.851	0.0524
			4.8	5.21E-02	1.8881		
			4.9	5.10E-02	1.8496		
			4.8	5.21E-02	1.8881		

Table C7 2,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	147	1.70E-03	0.1490	0.151	0.0018
			145	1.72E-03	0.1510		
			143	1.75E-03	0.1531		
			144	1.74E-03	0.1521		
	100	0.25	61	4.10E-03	0.1486	0.151	0.0065
			59	4.24E-03	0.1536		
			63	3.97E-03	0.1439		
			57	4.39E-03	0.1590		
H2	50	0.25	7.5	3.33E-02	2.9200	2.910	0.0192
			7.5	3.33E-02	2.9200		
			7.6	3.29E-02	2.8816		
			7.5	3.33E-02	2.9200		
	100	0.25	3	8.33E-02	3.0210	3.127	0.0881
			2.8	8.93E-02	3.2368		
			2.9	8.62E-02	3.1251		
			2.9	8.62E-02	3.1251		
CH_4	50	0.25	430	5.81E-04	0.0509	0.050	0.0003
			435	5.75E-04	0.0503		
			435	5.75E-04	0.0503		
			435	5.75E-04	0.0503		
	100	0.25	170	1.47E-03	0.0533	0.051	0.0018
			180	1.39E-03	0.0503		
			185	1.35E-03	0.0490		
			180	1.39E-03	0.0503		
CO_2	50	0.25	10.2	2.45E-02	2.1470	2.116	0.0264
			10.3	2.43E-02	2.1262		
			10.4	2.40E-02	2.1058		
			10.5	2.38E-02	2.0857		
	100	0.25	4.2	5.95E-02	2.1578	2.121	0.0471
			4.2	5.95E-02	2.1578		
			4.4	5.68E-02	2.0598		
			4.3	5.81E-02	2.1077		

Table C8 Selectivity for asymmetric MMMs at 50 psi and 10% liquid loading

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
Ultem	30.74	1.39	30.92	22.18
20 % AC	40.15	2.48	21.34	16.21
PEG + AC	49.83	2.29	21.94	21.81
1,2 + AC	43.71	2.63	21.59	16.60
1,3 + AC	38.93	2.30	20.66	16.90
1,4 + AC	39.90	2.49	20.15	16.03
2,3 + AC	41.91	3.00	19.23	13.99

Table C9 Selectivity for asymmetric MMMs at 100 psi and 10% liquid loading

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
Ultem	29.86	1.40	31.11	21.36
20 % AC	40.20	2.47	21.67	16.25
PEG + AC	49.00	2.41	20.44	20.32
1,2 + AC	43.59	2.60	21.47	16.80
1,3 + AC	38.29	2.24	20.62	17.07
1,4 + AC	38.85	2.37	20.04	16.37
2,3 + AC	41.79	2.98	20.67	14.02

Appendix D The experimental flow rate of methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2) and hydrogen (H_2) of asymmetric membrane and mixed matrix membranes in performance at pressure of 50 and 100 psi and 20% liquid loading (only butanediol isomers).

Table D1 1,2-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	171	1.46E-03	0.1281	0.127	0.0006
			172	1.45E-03	0.1273		
			173	1.45E-03	0.1266		
			172	1.45E-03	0.1273		
	100	0.25	71	3.52E-03	0.1276	0.129	0.0032
			72	3.47E-03	0.1259		
			68	3.68E-03	0.1333		
			70	3.57E-03	0.1295		
H2	50	0.25	7.7	3.25E-02	2.8441	2.799	0.0344
			7.9	3.16E-02	2.7721		
			7.8	3.21E-02	2.8077		
			7.9	3.16E-02	2.7721		
	100	0.25	3.1	8.06E-02	2.9235	2.834	0.0724
			3.2	7.81E-02	2.8322		
			3.3	7.58E-02	2.7463		
			3.2	7.81E-02	2.8322		
CH_4	50	0.25	445	5.62E-04	0.0492	0.050	0.0005
			435	5.75E-04	0.0503		
			438	5.71E-04	0.0500		
			441	5.67E-04	0.0497		
	100	0.25	184	1.36E-03	0.0493	0.050	0.0005
			185	1.35E-03	0.0490		
			182	1.37E-03	0.0498		
			181	1.38E-03	0.0501		
CO_2	50	0.25	9.4	2.66E-02	2.3298	2.294	0.0410
			9.5	2.63E-02	2.3053		
			9.5	2.63E-02	2.3053		
			9.8	2.55E-02	2.2347		
	100	0.25	4	6.25E-02	2.2657	2.252	0.0276
			4.1	6.10E-02	2.2105		
			4	6.25E-02	2.2657		
			4	6.25E-02	2.2657		

Table D2 1,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	242	1.03E-03	0.0905	0.090	0.0013
			248	1.01E-03	0.0883		
			240	1.04E-03	0.0912		
			241	1.04E-03	0.0909		
	100	0.25	99	2.53E-03	0.0915	0.092	0.0016
			100	2.50E-03	0.0906		
			96	2.60E-03	0.0944		
			98	2.55E-03	0.0925		
H2	50	0.25	11.5	2.17E-02	1.9043	1.812	0.0630
			12.4	2.02E-02	1.7661		
			12.2	2.05E-02	1.7951		
			12.3	2.03E-02	1.7805		
	100	0.25	4.7	5.32E-02	1.9283	1.844	0.0982
			5.2	4.81E-02	1.7429		
			5.1	4.90E-02	1.7770		
			4.7	5.32E-02	1.9283		
CH_4	50	0.25	541	4.62E-04	0.0405	0.041	0.0003
			544	4.60E-04	0.0403		
			535	4.67E-04	0.0409		
			540	4.63E-04	0.0406		
	100	0.25	225	1.11E-03	0.0403	0.041	0.0003
			223	1.12E-03	0.0406		
			221	1.13E-03	0.0410		
			222	1.13E-03	0.0408		
CO_2	50	0.25	12.6	1.98E-02	1.7381	1.701	0.0253
			13	1.92E-02	1.6846		
			12.9	1.94E-02	1.6977		
			13	1.92E-02	1.6846		
	100	0.25	5.5	4.55E-02	1.6478	1.691	0.0506
			5.5	4.55E-02	1.6478		
			5.25	4.76E-02	1.7263		
			5.2	4.81E-02	1.7429		

Table D3 1,4-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	212	1.18E-03	0.1033	0.104	0.0011
			209	1.20E-03	0.1048		
			211	1.18E-03	0.1038		
			207	1.21E-03	0.1058		
	100	0.25	85	2.94E-03	0.1066	0.106	0.0011
			86	2.91E-03	0.1054		
			84.5	2.96E-03	0.1073		
			86.5	2.89E-03	0.1048		
H2	50	0.25	10.1	2.48E-02	2.1683	2.185	0.0375
			9.8	2.55E-02	2.2347		
			10.2	2.45E-02	2.1470		
			10	2.50E-02	2.1900		
	100	0.25	4.22	5.92E-02	2.1476	2.191	0.0535
			4.2	5.95E-02	2.1578		
			4.13	6.05E-02	2.1944		
			4	6.25E-02	2.2657		
CH_4	50	0.25	485	5.15E-04	0.0452	0.045	0.0004
			489	5.11E-04	0.0448		
			495	5.05E-04	0.0442		
			490	5.10E-04	0.0447		
	100	0.25	203	1.23E-03	0.0446	0.045	0.0005
			198	1.26E-03	0.0458		
			201	1.24E-03	0.0451		
			202	1.24E-03	0.0449		
CO_2	50	0.25	12	2.08E-02	1.8250	1.814	0.0143
			12.1	2.07E-02	1.8099		
			12	2.08E-02	1.8250		
			12.2	2.05E-02	1.7951		
	100	0.25	4.8	5.21E-02	1.8881	1.823	0.0468
			5.1	4.90E-02	1.7770		
			5	5.00E-02	1.8126		
			5	5.00E-02	1.8126		

Table D4 2,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	162	1.54E-03	0.1352	0.136	0.0019
			163	1.53E-03	0.1344		
			158	1.58E-03	0.1386		
			160	1.56E-03	0.1369		
	100	0.25	66	3.79E-03	0.1373	0.138	0.0020
			67	3.73E-03	0.1353		
			65	3.85E-03	0.1394		
			65	3.85E-03	0.1394		
H2	50	0.25	7.75	3.23E-02	2.8258	2.854	0.0240
			7.6	3.29E-02	2.8816		
			7.65	3.27E-02	2.8627		
			7.7	3.25E-02	2.8441		
	100	0.25	3.1	8.06E-02	2.9235	2.949	0.0907
			3.2	7.81E-02	2.8322		
			3	8.33E-02	3.0210		
			3	8.33E-02	3.0210		
CH_4	50	0.25	421	5.94E-04	0.0520	0.052	0.0002
			420	5.95E-04	0.0521		
			418	5.98E-04	0.0524		
			422	5.92E-04	0.0519		
	100	0.25	171	1.46E-03	0.0530	0.053	0.0015
			165	1.52E-03	0.0549		
			168	1.49E-03	0.0539		
			176	1.42E-03	0.0515		
CO_2	50	0.25	9.5	2.63E-02	2.3053	2.252	0.0398
			9.7	2.58E-02	2.2577		
			9.8	2.55E-02	2.2347		
			9.9	2.53E-02	2.2121		
	100	0.25	4.1	6.10E-02	2.2105	2.296	0.0618
			3.9	6.41E-02	2.3238		
			3.95	6.33E-02	2.2944		
			3.85	6.49E-02	2.3540		

Table D5 Selectivity for asymmetric MMMs at 50 psi and 20% liquid loading

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
Ultem	30.74	1.39	30.92	22.18
20 % AC	40.15	2.48	21.34	16.21
PEG + AC	49.83	2.29	21.94	21.81
1,2 + AC	46.06	2.56	21.98	18.01
1,3 + AC	41.95	2.22	20.08	18.85
1,4 + AC	40.56	2.33	20.93	17.37
2,3 + AC	43.22	2.61	20.94	16.53

Table D6 Selectivity for asymmetric MMMs at 100 psi and 20% liquid loading

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
Ultem	29.86	1.40	31.11	21.36
20 % AC	40.20	2.47	21.67	16.25
PEG + AC	49.00	2.41	20.44	20.32
1,2 + AC	45.47	2.61	21.95	17.45
1,3 + AC	41.56	2.27	19.99	18.33
1,4 + AC	40.42	2.35	20.67	17.19
2,3 + AC	43.04	2.58	21.39	16.65

Appendix E The experimental flow rate of methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2) and hydrogen (H_2) of asymmetric membrane and mixed matrix membranes in performance at pressure of 50 and 100 psi and 30% liquid loading (only butanediol isomers).

Table E1 1,2-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	189.2	1.32E-03	0.1157	0.116	0.0006
			189.3	1.32E-03	0.1157		
			188.3	1.33E-03	0.1163		
			190.5	1.31E-03	0.1150		
	100	0.25	78.2	3.20E-03	0.1159	0.116	0.0013
			79.5	3.14E-03	0.1140		
			77.4	3.23E-03	0.1171		
			77.9	3.21E-03	0.1163		
H2	50	0.25	8.5	2.94E-02	2.5765	2.631	0.0544
			8.3	3.01E-02	2.6385		
			8.4	2.98E-02	2.6071		
			8.1	3.09E-02	2.7037		
	100	0.25	3.2	7.81E-02	2.8322	2.636	0.1821
			3.7	6.76E-02	2.4494		
			3.6	6.94E-02	2.5175		
			3.3	7.58E-02	2.7463		
CH_4	50	0.25	458	5.46E-04	0.0478	0.048	0.0002
			455	5.49E-04	0.0481		
			455	5.49E-04	0.0481		
			455	5.49E-04	0.0481		
	100	0.25	185	1.35E-03	0.0490	0.049	0.0000
			185	1.35E-03	0.0490		
			185	1.35E-03	0.0490		
			185	1.35E-03	0.0490		
CO_2	50	0.25	9.5	2.63E-02	2.3053	2.305	0.0198
			9.6	2.60E-02	2.2812		
			9.4	2.66E-02	2.3298		
			9.5	2.63E-02	2.3053		
	100	0.25	3.9	6.41E-02	2.3238	2.309	0.0290
			3.9	6.41E-02	2.3238		
			3.9	6.41E-02	2.3238		
			4	6.25E-02	2.2657		

Table E2 1,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	260.3	9.60E-04	0.0841	0.083	0.0010
			268.2	9.32E-04	0.0817		
			264.4	9.46E-04	0.0828		
			262.9	9.51E-04	0.0833		
	100	0.25	102.8	2.43E-03	0.0882	0.088	0.0009
			101.7	2.46E-03	0.0891		
			102.5	2.44E-03	0.0884		
			104.3	2.40E-03	0.0869		
H2	50	0.25	12.6	1.98E-02	1.7381	1.725	0.0191
			12.7	1.97E-02	1.7244		
			12.6	1.98E-02	1.7381		
			12.9	1.94E-02	1.6977		
	100	0.25	4.55	5.49E-02	1.9918	1.825	0.1415
			5.4	4.63E-02	1.6783		
			5.2	4.81E-02	1.7429		
			4.8	5.21E-02	1.8881		
CH_4	50	0.25	544	4.60E-04	0.0403	0.040	0.0002
			542	4.61E-04	0.0404		
			547	4.57E-04	0.0400		
			540	4.63E-04	0.0406		
	100	0.25	222	1.13E-03	0.0408	0.041	0.0009
			224	1.12E-03	0.0405		
			220.5	1.13E-03	0.0411		
			213	1.17E-03	0.0425		
CO_2	50	0.25	12.5	2.00E-02	1.7520	1.718	0.0281
			12.8	1.95E-02	1.7109		
			12.7	1.97E-02	1.7244		
			13	1.92E-02	1.6846		
	100	0.25	5.3	4.72E-02	1.7100	1.727	0.0335
			5.3	4.72E-02	1.7100		
			5.3	4.72E-02	1.7100		
			5.1	4.90E-02	1.7770		

Table E3 1,4-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	222	1.13E-03	0.0986	0.099	0.0040
			224	1.12E-03	0.0978		
			228	1.10E-03	0.0961		
			208	1.20E-03	0.1053		
	100	0.25	89.5	2.79E-03	0.1013	0.102	0.0013
			88.4	2.83E-03	0.1025		
			89.6	2.79E-03	0.1011		
			87.2	2.87E-03	0.1039		
H2	50	0.25	10.5	2.38E-02	2.0857	2.087	0.0487
			10.2	2.45E-02	2.1470		
			10.8	2.31E-02	2.0278		
			10.5	2.38E-02	2.0857		
	100	0.25	4.37	5.72E-02	2.0739	2.091	0.0673
			4.48	5.58E-02	2.0230		
			4.35	5.75E-02	2.0834		
			4.15	6.02E-02	2.1838		
CH_4	50	0.25	532	4.70E-04	0.0412	0.041	0.0002
			525	4.76E-04	0.0417		
			528	4.73E-04	0.0415		
			527	4.74E-04	0.0416		
	100	0.25	211	1.18E-03	0.0430	0.042	0.0011
			212.5	1.18E-03	0.0426		
			210	1.19E-03	0.0432		
			222	1.13E-03	0.0408		
CO_2	50	0.25	12.1	2.07E-02	1.8099	1.833	0.0269
			11.7	2.14E-02	1.8718		
			12	2.08E-02	1.8250		
			12	2.08E-02	1.8250		
	100	0.25	4.7	5.32E-02	1.9283	1.852	0.0690
			4.8	5.21E-02	1.8881		
			5	5.00E-02	1.8126		
			5.1	4.90E-02	1.7770		

Table E4 2,3-butanediol/AC MMMs

Gas	P (psia)	vol. (ml)	time (sec)	Flow rate (ml/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
N_2	50	0.25	180.5	1.39E-03	0.1213	0.123	0.0012
			176.5	1.42E-03	0.1241		
			179.2	1.40E-03	0.1222		
			178.3	1.40E-03	0.1228		
	100	0.25	71.3	3.51E-03	0.1271	0.126	0.0019
			72.4	3.45E-03	0.1252		
			73.6	3.40E-03	0.1231		
			71.2	3.51E-03	0.1273		
H2	50	0.25	8.32	3.00E-02	2.6322	2.645	0.0287
			8.15	3.07E-02	2.6871		
			8.35	2.99E-02	2.6227		
			8.3	3.01E-02	2.6385		
	100	0.25	3.22	7.76E-02	2.8146	2.774	0.0476
			3.25	7.69E-02	2.7886		
			3.35	7.46E-02	2.7053		
			3.25	7.69E-02	2.7886		
CH_4	50	0.25	451	5.54E-04	0.0486	0.049	0.0004
			450	5.56E-04	0.0487		
			457	5.47E-04	0.0479		
			448	5.58E-04	0.0489		
	100	0.25	180	1.39E-03	0.0503	0.050	0.0006
			182	1.37E-03	0.0498		
			185	1.35E-03	0.0490		
			181	1.38E-03	0.0501		
CO_2	50	0.25	9.4	2.66E-02	2.3298	2.264	0.0450
			9.8	2.55E-02	2.2347		
			9.8	2.55E-02	2.2347		
			9.7	2.58E-02	2.2577		
	100	0.25	3.9	6.41E-02	2.3238	2.280	0.0290
			4	6.25E-02	2.2657		
			4	6.25E-02	2.2657		
			4	6.25E-02	2.2657		

Table E5 Selectivity for asymmetric MMMs at 50 psi and 30% liquid loading

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
1,2AC	47.98	2.41	22.75	19.93
1,3AC	42.62	2.06	20.78	20.70
1,4AC	44.19	2.40	20.98	18.43
2,3AC	46.68	2.53	21.57	18.47

Table E6 Selectivity for asymmetric MMMs at 100 psi and 30% liquid loading

Type of membrane	Selectivity for			
	CO_2/CH_4	N_2/CH_4	H_2/N_2	CO_2/N_2
1,2AC	47.14	2.36	22.76	19.94
1,3AC	41.88	2.14	20.71	19.59
1,4AC	43.67	2.41	20.46	18.11
2,3AC	45.79	2.52	22.07	18.14

Appendix F Other Summary Tables.

Table F1 %liquid loading at 50 psia for MMMs

% liquid loading	CO_2 Permeance (GPU) at 50 psi			
	1,2AC	1,3AC	1,4AC	2,3AC
10	2.281	1.669	1.800	2.116
20	2.294	1.701	1.814	2.252
30	2.305	1.718	1.833	2.264
40	-	-	-	-

Table F2 Energy between hydroxyl group in each type of glycol isomers.

Type of diol isomers	Enthalpy (J•kg•mol-2)
1,2ED	370
1,2PD	590
1,3BD	750
1,4BD	780
2,3BD	820
1,2BD	900

CURRICULUM VITAE

Name: Thanakorn Santiworawut

Date of Birth: March 20, 1985

Nationality: Thai

University Education:

2007-2009 Master of Science in Petrochemical Technology, The Petroleum and Petrochemical College, Chulalongkorn University, Thailand.

2003-2007 Bachelor Degree of Chemical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand.

Work Experience:

Sep. 2008-Nov. 2008 Position : Internship student

Company name: UOP, A Honeywell company LLC (Des Planines, IL, USA)

Presentations:

1. Santiworawut, T., Rirksomboon, T., and Kulprathipanja, S. (April 22, 2009) Mixed Matrix Membranes for Gas Separation: Effects of Various Glycols Incorporated into Activated Carbon and Ultem. Proceedings of The 15th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.
2. Santiworawut, T., Rirksomboon, T., and Kulprathipanja, S. (November 4-9, 2008,) Mixed Matrix Membranes for Gas Separation. Poster presented at AIChE Annual Meeting 2008, Philadelphia, USA.