REFERENCES

Abedini, R., and Nezhadmoghadam, A. (2010) Application of membrane in gas separation processes: Its suitability and mechanisms. Petroleum & Coal, 52(2), 69-80.

Allen, J.D., and Ishida, H. (2006) Physical and mechanical properties of flexible polybenzoxazine resins: effect of aliphatic diamine chain length. Journal of Applied Polymer Science, 101(5), 2798-2809.

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(1-2), 19–28.

Bao, L., Dorgan, J.R., Knauss, D., Hait, S., Oliveira, N.S., and Maruccho, I.M. (2006) Gas permeation properties of poly(lactic acid) revisited. Journal of Membrane Science, 285(1-2), 166–172.

Beck, J.S., Vartuli, C.J., Roth, J.W., Leonowicz, M.E., Kresge, C.T., Schmitt, K.D., Chu, C.T-W., Olson, D.H., Sheppard, E.W., McCullen, S.B., Higgins, J.B., and Schlenker, J.L. (1992) A new family of mesoporous molecular sieves prepared with liquid crystal templates. J. Am. Chem. Soc., 114(27), 10834-10843.

Chew, T-L., Ahmad, A.L., Bhatia, S. (2010) Ordered mesoporous silica (OMS) as an adsorbent and membrane for separation of carbon dioxide (CO_2). Advances in Colloid and Interface Science, 153(1-2), 43–57.

Devaraju, S., Vengatesan, M.R., Ashok Kumar, A., and Alagar, M. (2011) Polybenzoxazine–silica (PBZ–SiO_2) hybrid nanocomposites through in situ sol–gel method. J. Sol-Gel Sci. Technol., 60(1), 33-40.

Dhingra, S.S. (1997) Mixed gas transport study though polymeric membranes: a novel technique. Ph.D., The Virginia Polytechnic Institute and State University.

Hashemifard, S.A., Ismail, A.F., and Matsuura, T. (2011) Mixed matrix membrane incorporated with large pore size halloysite nanotubes (HNT) as filler for gas separation: experimental. Journal of Colloid and Interface Science, 359(2), 359-370.

Hu, C.C., Liu, T.C., Lee, K.R., Ruaan, R.C., and Lai, J.Y. (2006) Zeolite-filled PMMA composite membranes: influence of coupling agent addition on gas separation properties. Desalination, 193(1-3), 14-24.

Jang, H.T., Park, Y.K., Ko, Y.S., Lee, J.Y., and Margandan, B. (2009) Highly siliceous MCM-48 from rice husk ash for CO_2 adsorption. International Journal of Greenhouse Gas Control, 3(5), 545–549.

Kim, S., Ida, J., Guliants, V.V. and Lin, J.Y.S. (2005) Tailoring pore properties of MCM-48 silica for selective adsorption of CO_2. J. Phys. Chem. B., 109(13), 6287-6293.

Kim, S., Marand, E, Ida, J. and Guliants, V.V. (2006) Polysulfone and mesoporous molecular sieve MCM-48 mixed matrix membranes for gas separation. Chem. Mater., 18(5), 1149-1155.

Kim, S., and Marand, E. (2008) High permeability nano-composite membranes based on mesoporous MCM-41 nanoparticles in a polysulfone matrix. Microporous and Mesoporous Materials, 114(1-3), 129–136.

Longloilert, R., Chaisuwan, T., Luengnaruemitchai, A., and Wongkasemjit, S. (2011) Synthesis of MCM-48 from silatrane via sol–gel process. J. Sol-Gel Sci. Technol., 58(2), 427–435.

Mahajan, R., Burns, R., Schaeffer, M., and Koros, J.W. (2002) Challenges in forming successful mixed matrix membranes with rigid polymeric materials. Journal of Applied Polymer Science, 86(4), 881-890.

Nishiyama, N., Park, D.H., Koide, A., Egashira, Y., and Ueyama, K. (2001) A mesoporous silica (MCM-48) membrane: preparation and characterization. Journal of Membrane Science, 182(1-2), 235-244.

Pakkethati, K., Boonmalert, A., Chaisuwan, T., and Wongkasemjit, S. (2011) Development of polybenzoxazine membranes for ethanol–water separation via pervaporation. Desalination, 267(1), 73–81.

Perez, E.V., Balkus Jr, K.J., Ferraris, J.P., and Musselman, I.H. (2009) Mixed-matrix membranes containing MOF-5 for gas separations. Journal of Membrane Science, 328(1-2), 165–173.

Ployangoonsri, N. (2010) Hybrid polybenzoxazine composite membrane for CO_2/CH_4 separation. The Petroleum and Petrochemical College, Chulalongkorn University.

Reid, B.D., Ruiz-Trevino, F.A., Musselman, I.H., Balkus, K.J., Ferraris, J.P. (2001) Gas permeability properties of polysulfone membranes containing the mesoporous molecular sieve MCM-41. Chem. Mater., 13(7), 2366-2373.

Reusch, W. "Molecular Structure & Bonding." Molecular Shape. June 2010. 12 March 2012 <http://www2.chemistry.msu.edu/faculty/reusch/VirtTxtJml/intro3.htm>

Rutherford, S.W., and Do, D.D. (1997) Review of time lag permeation technique as a method for characterisation of porous media and membranes. Adsorption, 3(4), 283-312.

Sakamoto, Y., Nagata, K., Yogo, K., and Yamada, K. (2007) Preparation and CO_2 separation properties of amine-modified mesoporous silica membranes. Microporous and Mesoporous Materials, 101(1-2), 303–311.

Scholes, C.A., Kentish, S.E., and Stevens, G.W. (2008) Carbon dioxide separation through polymeric membrane systems for flue gas applications. Chemical Engineering, 1(1), 52-66.

Shao, Y., Wang, L., Zhang, J., and Anpo, M. (2005) Novel synthesis of high hydrothermal stability and long-range order MCM-48 with a convenient method. Microporous and Mesoporous Materials, 86(1-3), 314–322.

Takeichi, T., Kano, T., and Agag, T. (2005) Synthesis and thermal cure of high molecular weight polybenzoxazine precursors and the properties of the thermosets. Polymer, 46(26), 12172–12180.

Thanabodeekij, N., Sadthayanon S., Gulari, E., and Wongkasemjit, S. (2006) Extremely high surface area of ordered mesoporous MCM-41 by atrane route. Materials Chemistry and Physics, 96(2-3), 131-137.

Xing, R., and Ho, W.S.W. (2009) Synthesis and characterization of crosslinked polyvinylalcohol/polyethyleneglycol blend membranes for CO_2/CH_4 separation. Journal of the Taiwan Institute of Chemical Engineers, 40(6), 654–662.

Zhang, X., Shao, X., Wang, W., and Cao, D. (2010) Molecular modeling of selectivity of single-walled carbon nanotube and MCM-41 for separation of methane and carbon dioxide. Separation and Purification Technology, 74(3), 280–287.

Zhang, Y., Balkus Jr, K.J., Musselman, I.H., and Ferraris, J.P. (2008) Mixed-matrix membranes composed of Matrimid® and mesoporous ZSM-5 nanoparticles. Journal of Membrane Science, 325(1), 28–39.

Zimmerman, C.M., Singh, A., and Koros, W.J. (1997) Tailoring mixed matrix composite membranes for gas separations. J. Membr. Sci., 137(1-2), 145-154.

Zornoza, B., Irusta, S., Téllez, C., Coronas, J. (2009) Mesoporous silica sphere-poly sulfone mixed matrix membranes for gas separation, Langmuir, 25(10), 5903–5909.

Zornoza, B., Téllez, C., and Coronas, J. (2011) Mixed matrix membranes comprising glassy polymers and dispersed mesoporous silica spheres for gas separation. Journal of Membrane Science, 368(1-2), 100–109.

APPENDIX

Appendix A Experimental Flow Rate of CH_4 and CO_2 of MMMs

Table A1 10 wt% MCM-48/PBZ MMMs

Gas	Flow rate (cm^3/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
CH_4	2.117	370.757	452.50	94.03
	3.350	586.788		
	2.917	510.885		
	2.133	373.676		
	2.400	420.385		
CO_2	1.338	234.423	255.27	54.60
	1.833	321.128		
	1.683	294.854		
	1.035	181.291		
	1.397	244.641		

Table A2 15 wt% MCM-48/PBZ MMMs

Gas	Flow rate (cm^3/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
CH_4	7.417	1299.108	1304.95	23.08
	7.633	1337.059		
	7.350	1287.430		
	7.317	1281.591		
	7.533	1319.543		
CO_2	4.333	759.029	770.12	52.65
	4.017	703.562		
	4.667	817.416		
	4.233	741.513		
	4.733	829.093		

Table A3 20 wt% MCM-48/PBZ MMMs

Gas	Flow rate (cm^3/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
CH_4	12.450	2180.749	2144.55	37.87
	12.400	2171.991		
	12.333	2160.314		
	11.950	2093.169		
	12.083	2116.523		
CO_2	6.517	1141.463	1331.80	108.52
	7.800	1366.252		
	7.833	1372.091		
	7.783	1363.333		
	8.083	1415.881		

Table A4 10 wt% MCM-41/PBZ MMMs

Gas	Flow rate (cm^3/sec)	Permeance (GPU)	Average of Permeance (GPU)	STDEV of Permeance
CH_4	0.142	24.902	22.04	3.13
	0.112	19.530		
	0.102	17.925		
	0.133	23.296		
	0.140	24.552		
CO_2	1.058	185.378	182.58	20.73
	1.005	176.036		
	0.865	151.514		
	1.182	206.981		
	1.102	192.969		

Table A5 CH_4/CO_2 Selectivity of MMMs

Filler	wt%	Permeance (GPU)		Selectivity	Average of selectivity	STDEV of selectivity
		CH_4	CO_2			
MCM-48	10	370.757	234.423	1.58	1.78	0.18
		586.788	321.128	1.83		
		510.885	294.854	1.73		
		373.676	181.291	2.06		
		420.385	244.641	1.72		
	15	1299.108	759.029	1.71	1.70	0.13
		1337.059	703.562	1.90		
		1287.430	817.416	1.58		
		1281.591	741.513	1.73		
		1319.543	829.093	1.59		
	20	2180.749	1141.463	1.91	1.62	0.17
		2171.991	1366.252	1.59		
		2160.314	1372.091	1.57		
		2093.169	1363.333	1.54		
		2116.523	1415.881	1.49		
MCM-41	10	24.902	185.378	0.13	0.12	0.01
		19.530	176.036	0.11		
		17.925	151.514	0.12		
		23.296	206.981	0.11		
		24.552	192.969	0.13		

CURRICULUM VITAE

Name: Ms. Nuttheewan Kittisarunlerd

Date of Birth: July 19, 1988

Nationality: Thai

University Education:

2006-2010 Bachelor Degree of Engineering Program in Petrochemical and Polymeric Materials, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakornpatom, Thailand

Proceedings:

1. Kittisarunlerd, N.; Chaisuwan, T.; and Wongkasemjit, S. (2012, April 24) MCM-48-Polybenzoxazine mixed matrix membranes for CH_4/CO_2 separation. Proceedings of the 3rd Research Symposium on Petrochemical and Materials Technology and the 18th PPC Symposium on Petroleum, Petrochemicals and Polymers, Ballroom, Queen Sirikit National Convention Center, Bangkok, Thailand.

Presentations:

1. Kittisarunlerd, N.; Chaisuwan, T.; and Wongkasemjit, S. (2012, March 25-29) MCM-48-Polybenzoxazine mixed matrix membranes for CH_4/CO_2 separation. Paper presented at the 243rd ACS National Meeting & Exposition, San Diego, CA, USA.
2. Kittisarunlerd, N.; Chaisuwan, T.; and Wongkasemjit, S. (2012, April 24) MCM-48-Polybenzoxazine mixed matrix membranes for CH_4/CO_2 separation. Paper presented at the 3rd Research Symposium on Petrochemical and Materials Technology and the 18th PPC Symposium on Petroleum, Petrochemicals and Polymers, Bangkok, Thailand.