REFERENCES

Adeleye, S.A., Rautiu, R., White, D.A., and Clay, P.G. (1995) Clay Minerals as Sorbents for Nuclear Reactor Activation Products. Journal of Materials Science, 30(3), 583-586.

Armbruster, T. (1996) Clinoptilolite-Heulandite: Applications and Basic Research. Studied in Surface Science and Catalysis, 135, 13-24.

Blanca, E.J., Vaca-Mier, M., Lopez, C.R., Gehr, R., and Alvarez, P.J.J. (2001) Heavy Metal Removal with Mexican Clinoptilolite: Multi-Component Ionic Exchange. Water Resources Journal, 35, 373-378.

Bowman, R.S., Sullivan E.J., and Li Z. (1997) Mechanisms of Contaminant Sorption by Surfactant-Modified Zeolite. In Proc. WERC/HSRC '97 Joint Conference on the Environment, 22-24 April 1997, Albuquerque, NM, 104-108.

Cadena, F. and Bowman, R.S. (1994) Simultaneous Removal of Anionic, Cationic and Neutral Hazardous Pollutant from Solutions. Environmental Science and Technologies, 28, 302-311.

Chen, Y.L., Chen, S., Frank, C., and Israelachvili, J. (1992) Molecular Mechanisms and Kinetics During the Self-Assembly of Surfactant Layers. Colloid Interface Science, 153, 244-265.

Derakhshan, N. (1999) Comparison of Activated Carbons and Clays for the Removal of Organic Contaminants from Water. www.cheque.uq.edu.au/ugrad/theses/1999/authors/N_Derakhshan.htm.

Fuierer, A.M., Bowman, R.S., and Kieft, T.L. (2001) Enhanced In Situ Biodegradation of Organic Contaminants Using a Surfactant-Modified Zeolite Support. www.werc.net/researchers/pdf/bowman00.pdf

Li, Z. and Bowman, R.S. (1997) Counterion Effects on the Sorption of Cationic Surfactant and Chromate on Natural Clinoptilolite. Environmental Science and Technologies, 31, 2407-2412.

Li, Z. and Bowman, R.S. (1998) Sorption of Perchloroethylene by Surfactant-Modified Zeolite as Controlled by Surfactant Loading. Environmental Science and Technologies, 32, 2278-2282.

Li, Z., Anghel, I., and Bowman, R.S. (1998) Sorption of Oxyanions by Surfactant-Modified Zeolite. Dispersion Science and Technology, 19, 843-857.

Li, Z., Roy, S., Zou, Y., and Bowman, R.S. (1998) Long-Term Chemical and Biological Stability of Surfactant-Modified Zeolite. Environmental Science and Technologies, 32, 2628-2632.

Li, Z. (1999) Sorption Kinetics of Hexadecyltrimethylammonium on Natural Clinoptilolite. Langmuir, 15, 6438-6445.

Li, Z., Burt, T., and Bowman, R.S. (2000) Sorption of Ionizable Organic Solutes by Surfactant-Modified Zeolite. Environmental Science and Technologies, 34, 3756-3760.

Li, Z. and Bowman, R.S. (2001) Regeneration of Surfactant-Modified Zeolite after Saturation with Chromate and Perchloroethylene. Environmental Science and Technologies, 35, 322-326.

Lo, M.C., Mak, R.K., and Lee, S.C. (1997) Modified Clays for Waste Containment and Pollutant Attenuation. Journal of Environmental Engineering, 123, 25-32.

Malakul, P., Srinivasan, K.R., and Wang, H.Y. (1998) Metal Adsorption and Desorption Characteristics of Surfactant-Modified Clay Complexes. Industrial & Engineering Chemistry: Research, 37, 4296-4301.

Malakul, P., Srinivasan, K.R., and Wang, H.Y. (1998) Metal Toxicity Reduction in Naphthalene Biodegradation by Use of Metal-Chelating Adsorbents. Applied and Environmental Microbiology, 64(11), 4610-4613.

Mier, M.V., Callejas, R.L., Gehr, R., Cisneros, B.E.J., and Alvarez, P.J.J. (2001) Heavy Metal Removal with Mexican Clinoptilolite : Multi-Component Ionic Exchange. Environmental Science and Technologies, 35(2), 373-378.

Narbaitz, R.M. (1994) Adsorption of 1,1,2-Trichloroethane from River Water. Journal of Environmental Engineering, 120(6), 1400-1415.

Nivas, B.T., Shiau, B.J., Sabatini, D.A., and Harwell, J.H. (1996) Surfactant Enhanced Remediation of Subsurface Chromium Contamination. Water Science Technology, 30, 511-520.

Ouki, S.K. and Kavannagh, M. (1999) Treatment of Metals-Contaminated Wastewaters by Use of Natural Zeolites. Water Science Technology, 36, 115-122.

Pradubmook, T., O'Haver, J.H., Malakul, P., and Harwell, J.H. (2003) Effect pH on Adsolubilization of Toluene and Acetophenone into Adsorbed Surfactant on Precipitated Silica. Colloids and Surfaces A. Physicochemical and Engineering Aspects, 224, 93-98.

Saengchote, S. (2003) Enhanced Sorption of Heavy Metal and Organic Contaminants Using Surfactant-Modified Zeolite (SMZ). M.S. Thesis in Petrochemical, The Petroleum and Petrochemical College, Chulalongkorn University.

Scamehorn, J.F., Schechter, R.S., and Wade, W.H. (1982) Adsorption of Surfactants on Mineral Oxide Surfaces from Aqueous solutions. Colloid Interface Science, 85(2), 463-477.

Sismanoglu, T. and Pura, S. (2001) Adsorption of Aqueous Nitrophenols on Clinoptilolite. Colloids and Surfaces, 180, 1-6.

Stephen, A.B., Jiunn, F.L., and Max, M.M. (1988) Atteunating Organic Contaminant Mobility by Soil Modification. Nature, 333, 345-347.

Sullivan, E.J., Hunter, D.B., and Bowman, R.S. (1998) Modified Clinoptilolite Studied by Tapping-Mode Atomic Force Microscopy and High-Resolution Thermo Gravimetric Analysis. http://www.ees.nmt.edu, 3/5/2002.

Sullivan, E.J., Carey, J.W., and Bowman, R.S. (1998) Thermodynamics of Cationic Surfactant Sorption onto Clinoptilolite. http://www.ees.nmt.edu, 3/5/2002.

White, D.A., Nattkemper, A., and Rautiu, R. (1999) Evaluation of the Effect of Temperature on Potassium Clinoptilolite Ion Exchange. Nuclear Technology, 127, 212-217.

Upmeier, M.W. and Czurda, K.A. (1997) Use of Clinoptilolite for the Optimization of Mineral Clay Liners for Waste Deposits. In CHON, H. (Ed.), Studies in Surface Science and Catalysis, 105, 1633-1639.

APPENDIX

Table A1 Adsorption isotherm of CTAB on clinoptilolite at 25°C

Weight of clinoptilolite = 0.2 g

Volume of CTAB solution = 20 ml

Molecular weight of CTAB = 364.46 g/mol

No.	$[CTAB]_{initial}$		$[CTAB]_{equilibrium}$		Amount of surfactant adsorbed (μmol/g)	S.D.
	μM	ppm	μM	ppm		
1	50	18.223	40.612	14.801	0.939	0.102
2	100	36.446	52.266	19.049	4.773	0.563
3	300	109.338	68.560	24.988	23.144	2.659
4	500	182.230	97.180	35.418	40.282	3.947
5	700	255.122	212.959	77.615	48.704	2.896
6	900	328.014	313.423	114.23	58.658	2.35
7	1000	364.460	389.383	141.915	61.062	4.461
8	1400	510.244	604.988	220.494	79.501	2.341
9	1800	656.028	977.685	356.327	82.232	3.215
10	2000	728.920	1171.261	426.878	82.874	3.556
11	2500	911.150	1666.720	607.453	83.328	3.875

Table A2 Zeta-Potential data for CTAB adsorption on clinoptilolite

No.	Amount of surfactant adsorbed (μmol/g)	zeta potential (mV)											S.D.
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	average	
1	0.00	-45.9	-47.2	-47.3	-42.5	-48.6	-41.6	-43.8	-44.8	-45.6	-46.2	-45.4	2.2
2	0.94	-43.8	-44.6	-42	-46.7	-45.3	-43.5	-45.8	-41.5	-44.4	-45.6	-44.3	1.7
3	4.77	-39.8	-40.7	-41.7	-40.8	-41.9	-37.1	-42.9	-42.7	-39.2	-38.5	-40.5	1.9
4	23.14	-24.2	-23.8	-22.6	-22.4	-24.7	-21.4	-22.5	-25.2	-20.8	-21.1	-22.9	1.5
5	40.28	2.6	5.2	6.2	4.5	2.8	4.9	6.0	3.7	2.2	3.1	4.1	1.4
6	48.70	19.6	21.3	17.5	19.5	16.7	18.4	20.7	21.6	17.5	18.4	19.1	1.7
7	58.66	27.2	26.9	25.6	25.8	26.1	26.2	27.1	24.3	23.9	26.6	26.0	1.1
8	61.06	26.7	27.1	31.2	29.1	27.6	30.3	25.9	27.4	26.7	29.5	28.2	1.8

Table A3 Adsorption isotherm of cadmium on SMZ with various PA:CTAB loading ratios

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

SMZ (0:1)						
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed	S.D.
	ppm	μM	ppm	μM	mg/g	
1	25	222.420	24.483	217.818	0.052	0.005
2	50	444.840	46.397	412.789	0.360	0.010
3	100	889.680	89.158	793.225	1.084	0.011
4	150	1334.520	137.704	1225.122	1.230	0.026
5	200	1779.359	187.380	1667.078	1.262	0.028
SMZ (1:1)						
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed	S.D.
	ppm	μM	ppm	μM	mg/g	
1	25	222.420	18.454	164.179	0.655	0.065
2	50	444.840	37.095	330.030	1.290	0.009
3	100	889.680	80.355	714.900	1.965	0.027
4	150	1334.520	126.740	1127.578	2.326	0.167
5	200	1779.359	174.685	1554.140	2.531	0.022
SMZ (2:1)						
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed	S.D.
	ppm	μM	ppm	μM	mg/g	
1	25	222.420	12.193	108.482	1.281	0.119
2	50	444.840	30.657	272.752	1.934	0.009
3	100	889.680	70.039	623.120	2.996	0.009
4	150	1334.520	115.525	1027.803	3.447	0.021
5	200	1779.359	165.425	1471.755	3.457	0.002
SMZ (4:1)						
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed	S.D.
	ppm	μM	ppm	μM	mg/g	
1	25	222.420	9.750	86.742	1.525	0.030
2	50	444.840	24.107	214.475	2.589	0.007
3	100	889.680	62.087	552.378	3.791	0.037
4	150	1334.520	108.333	963.818	4.167	0.034
5	200	1779.359	152.820	1359.607	4.718	0.102
SMZ (6:1)						
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed	S.D.
	ppm	μM	ppm	μM	mg/g	
1	25	222.420	11.068	98.471	1.393	0.032
2	50	444.840	24.964	222.100	2.504	0.102
3	100	889.680	60.072	534.448	3.993	0.077
4	150	1334.520	106.730	949.554	4.327	0.110
5	200	1779.359	154.491	1374.472	4.551	0.265

Table A4 Adsorption isotherm of toluene on SMZ with various PA:CTAB loading ratios

Weight of SMZ = 0.2 g

Volume of toluene solution = 20 ml

SMZ (0:1)						
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed	S.D.
	ppm	μM	ppm	μM	μmol/g	
1	46.071	500	37.784	410.062	8.994	1.088
2	138.213	1500	110.218	1196.180	30.382	2.690
3	276.426	3000	220.277	2390.626	60.937	0.426
4	414.639	4500	323.067	3506.189	99.381	7.661
5	552.852	6000	429.302	4659.135	134.087	3.521
SMZ (1:1)						
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed	S.D.
	ppm	μM	ppm	μM	μmol/g	
1	46.071	500	38.810	421.197	7.880	1.344
2	138.213	1500	116.471	1264.041	23.596	0.799
3	276.426	3000	225.787	2450.423	54.958	2.348
4	414.639	4500	330.770	3589.790	91.021	3.380
5	552.852	6000	436.402	4736.192	126.381	1.820
SMZ (2:1)						
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed	S.D.
	ppm	μM	ppm	μM	μmol/g	
1	46.071	500	38.238	414.985	8.502	0.302
2	138.213	1500	118.622	1287.379	21.261	0.566
3	276.426	3000	224.914	2440.946	55.905	0.471
4	414.639	4500	333.065	3614.697	88.530	2.967
5	552.852	6000	441.131	4787.512	121.249	1.824
SMZ (4:1)						
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed	S.D.
	ppm	μM	ppm	μM	μmol/g	
1	46.071	500	41.217	447.287	5.271	0.231
2	138.213	1500	121.483	1318.428	18.157	0.488
3	276.426	3000	228.664	2481.650	51.835	0.114
4	414.639	4500	337.902	3667.190	83.281	1.175
5	552.852	6000	445.934	4839.637	116.036	2.551

Table A5 Adsorption of cadmium on SMZ (4:1) in the presence of toluene

Weight of SMZ (4:1) = 0.2 g

Volume of mixed solutes solution = 20 ml

Initial cadmium concentration = 500 μM

Initial toluene concentration = 1500 μM

No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed
	μM	ppm	μM	ppm	mg/g
1	500	56.2	232.820	26.169	3.003
2	500	56.2	233.701	26.268	2.993
3	500	56.2	232.820	26.169	3.003
4	500	56.2	231.940	26.070	3.013
5	500	56.2	234.582	26.367	2.983
6	500	56.2	232.820	26.169	3.003
Average	500	56.2	233.114	26.202	3.000

Table A6 Adsorption of cadmium on SMZ (4:1) in the presence of toluene

Weight of SMZ (4:1) = 0.2 g

Volume of mixed solutes solution = 20 ml

Initial cadmium concentration = 1500 μM

Initial toluene concentration = 1500 μM

No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed
	μM	ppm	μM	ppm	mg/g
1	1500	168.6	1110.231	124.790	4.381
2	1500	168.6	1112.260	125.018	4.358
3	1500	168.6	1116.308	125.473	4.313
4	1500	168.6	1120.365	125.929	4.267
5	1500	168.6	1114.279	125.245	4.335
6	1500	168.6	1116.308	125.473	4.313
Average	1500	168.6	1114.958	125.321	4.328

Table A7 Adsorption of cadmium on SMZ (4:1) in the presence of toluene

Weight of SMZ (4:1) = 0.2 g

Volume of mixed solutes solution = 20 ml

Initial cadmium concentration = 1500 μM

Initial toluene concentration = 500 μM

No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed
	μM	ppm	μM	ppm	mg/g
1	1500	168.6	1122.384	126.156	4.244
2	1500	168.6	1124.413	126.384	4.222
3	1500	168.6	1122.384	126.156	4.244
4	1500	168.6	1122.384	126.156	4.244
5	1500	168.6	1120.365	125.929	4.267
6	1500	168.6	1124.413	126.384	4.222
Average	1500	168.6	1122.724	126.194	4.241

Table A8 Adsorption of toluene on SMZ (4:1) in the presence of cadmium

Weight of SMZ (4:1) = 0.2 g

Volume of mixed solutes solution = 20 ml

Initial cadmium concentration = 500 μM

Initial toluene concentration = 1500 μM

No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed (μmol/g)
	μM	ppm	μM	ppm	
1	1500	138.213	1273.487	117.342	22.651
2	1500	138.213	1272.378	117.239	22.762
3	1500	138.213	1283.593	118.273	21.641
4	1500	138.213	1278.529	117.806	22.147
5	1500	138.213	1282.473	118.170	21.753
6	1500	138.213	1277.307	117.694	22.269
Average	1500	138.213	1277.961	117.754	22.204

Table A9 Adsorption of toluene on SMZ (4:1) in the presence of cadmium

Weight of SMZ (4:1) = 0.2 g

Volume of mixed solutes solution = 20 ml

Initial cadmium concentration = 1500 μM

Initial toluene concentration = 1500 μM

No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed (μmol/g)
	μM	ppm	μM	ppm	
1	1500	138.213	1287.314	118.616	21.269
2	1500	138.213	1277.606	117.721	22.239
3	1500	138.213	1274.054	117.394	22.595
4	1500	138.213	1284.678	118.373	21.532
5	1500	138.213	1281.260	118.058	21.874
6	1500	138.213	1269.812	117.003	23.019
Average	1500	138.213	1279.121	117.861	22.088

Table A10 Adsorption of toluene on SMZ (4:1) in the presence of cadmium

Weight of SMZ (4:1) = 0.2 g

Volume of mixed solutes solution = 20 ml

Initial cadmium concentration = 1500 μM

Initial toluene concentration = 500 μM

No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed (μmol/g)
	μM	ppm	μM	ppm	
1	500	46.071	435.115	40.092	6.489
2	500	46.071	437.115	40.277	6.289
3	500	46.071	437.870	40.346	6.213
4	500	46.071	436.604	40.230	6.34
5	500	46.071	438.856	40.437	6.114
6	500	46.071	435.927	40.167	6.407
Average	500	46.071	436.915	40.258	6.309

Table A11 Adsorption and desorption of cadmium by SMZ (4:1)

Weight of SMZ (4:1) = 0.2 g

Volume of cadmium solution = 20 ml

Initial cadmium concentration = 200 ppm

Volume of acid solution = 20 ml

The adsorption and desorption of cadmium by SMZ was performed at pH 7 and pH 1.5, respectively.

1st adsorption cycle					
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed
	ppm	μM	ppm	μM	mg/g
1	200	1779.359	153.091	1362.020	4.691
2	200	1779.359	152.868	1360.036	4.713
3	200	1779.359	152.422	1356.068	4.758
4	200	1779.359	153.091	1362.020	4.691
5	200	1779.359	153.091	1362.020	4.691
6	200	1779.359	152.422	1356.068	4.758
Average	200	1779.359	152.831	1359.705	4.717
Desorption					
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} desorbed
	ppm	μM	ppm	μM	mg/g
1	0	0	18.759	166.895	1.876
2	0	0	18.677	166.165	1.868
3	0	0	18.841	167.625	1.884
4	0	0	18.677	166.165	1.868
5	0	0	18.595	165.436	1.860
6	0	0	17.612	156.690	1.761
Average	0	0	18.527	164.829	1.853
2nd adsorption cycle					
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed
	ppm	μM	ppm	μM	mg/g
1	200	1779.359	160.891	1431.415	3.911
2	200	1779.359	161.423	1436.148	3.858
3	200	1779.359	161.157	1433.781	3.884
4	200	1779.359	160.891	1431.415	3.911
5	200	1779.359	160.625	1429.048	3.937
6	200	1779.359	161.423	1436.148	3.858
Average	200	1779.359	161.068	1432.992	3.893

3rd adsorption cycle					
No.	$[Cd^{2+}]_{initial}$		$[Cd^{2+}]_{equilibrium}$		Amount of Cd^{2+} adsorbed
	ppm	μM	ppm	μM	mg/g
1	200	1779.359	167.068	1486.370	3.293
2	200	1779.359	166.540	1481.673	3.346
3	200	1779.359	166.275	1479.315	3.372
4	200	1779.359	167.068	1486.370	3.293
5	200	1779.359	166.804	1484.021	3.320
6	200	1779.359	166.275	1479.315	3.372
Average	200	1779.359	166.672	1482.844	3.333

Table A12 Adsorption and desorption of toluene by SMZ (4:1)

Weight of SMZ (4:1) = 0.2 g

Volume of toluene solution = 20 ml

Initial toluene concentration = 6000 μM

Desorption of toluene by SMZ was performed by air purging.

1st adsorption cycle					
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed
	ppm	μM	ppm	μM	μmol/g
1	552.852	6000	444.215	4820.983	117.902
2	552.852	6000	445.775	4837.913	116.209
3	552.852	6000	446.361	4844.273	115.573
4	552.852	6000	446.050	4840.901	115.911
5	552.852	6000	445.934	4839.639	116.036
6	552.852	6000	447.271	4854.149	114.585
Average	552.852	6000	445.934	4839.643	116.036
Desorption					
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene desorbed
	ppm	μM	ppm	μM	μmol/g
1	444.215	4820.983	0.432	4.688	117.794
2	445.775	4837.913	0.398	4.319	116.109
3	446.361	4844.273	0.401	4.352	115.473
4	446.050	4840.901	0.416	4.515	115.807
5	445.934	4839.639	0.405	4.395	115.935
6	447.271	4854.149	0.364	3.950	114.494
Average	445.934	4839.643	0.403	4.370	115.935

2nd adsorption cycle					
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed
	ppm	μM	ppm	μM	μmol/g
1	552.852	6000	455.936	4948.189	105.181
2	552.852	6000	454.775	4935.589	106.441
3	552.852	6000	456.809	4957.663	104.233
4	552.852	6000	455.512	4943.587	105.641
5	552.852	6000	454.978	4937.792	106.221
6	552.852	6000	456.280	4951.922	104.807
Average	552.852	6000	455.715	4945.790	105.421
3rd adsorption cycle					
No.	$[Toluene]_{initial}$		$[Toluene]_{equilibrium}$		Amount of toluene adsorbed
	ppm	μM	ppm	μM	μmol/g
1	552.852	6000	459.836	4990.515	100.949
2	552.852	6000	460.757	5000.510	99.949
3	552.852	6000	461.609	5009.757	99.024
4	552.852	6000	462.268	5016.909	98.309
5	552.852	6000	461.782	5011.634	98.836
6	552.852	6000	461.08	5004.016	99.598
Average	552.852	6000	461.222	5005.557	99.444

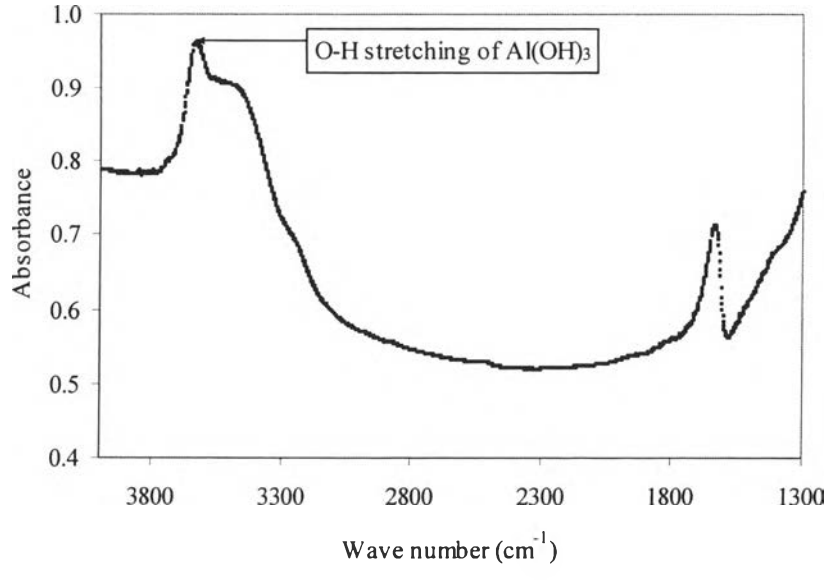

Figure A1 FTIR spectra of clinoptilolite

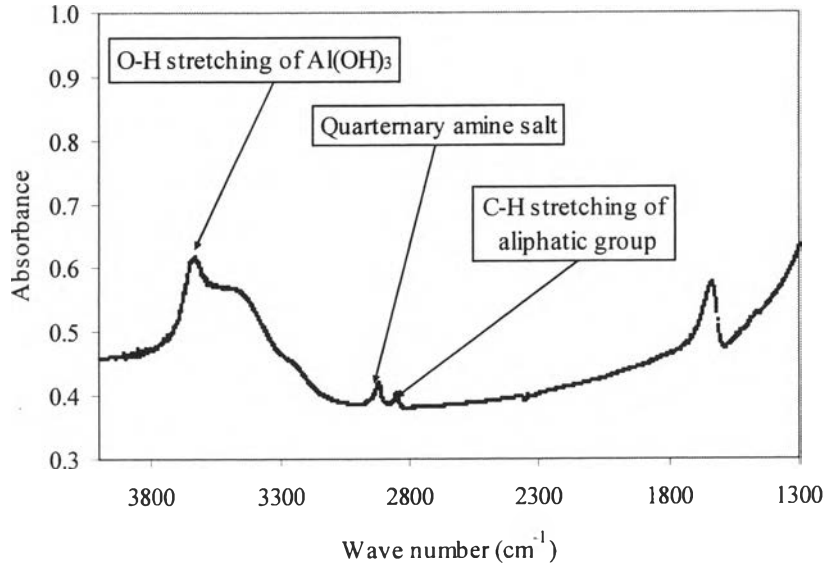

Figure A2 FTIR spectra of SMZ (0:1)

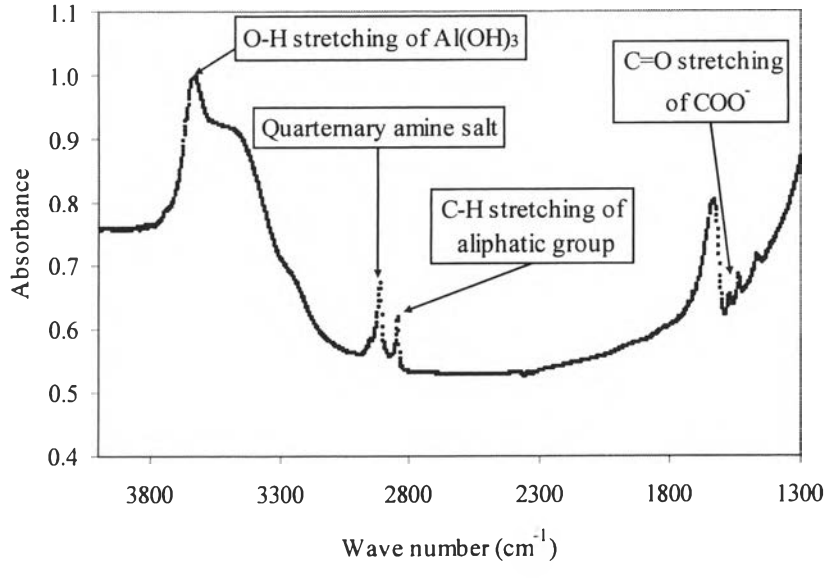

Figure A3 FTIR spectra of SMZ (1:1)

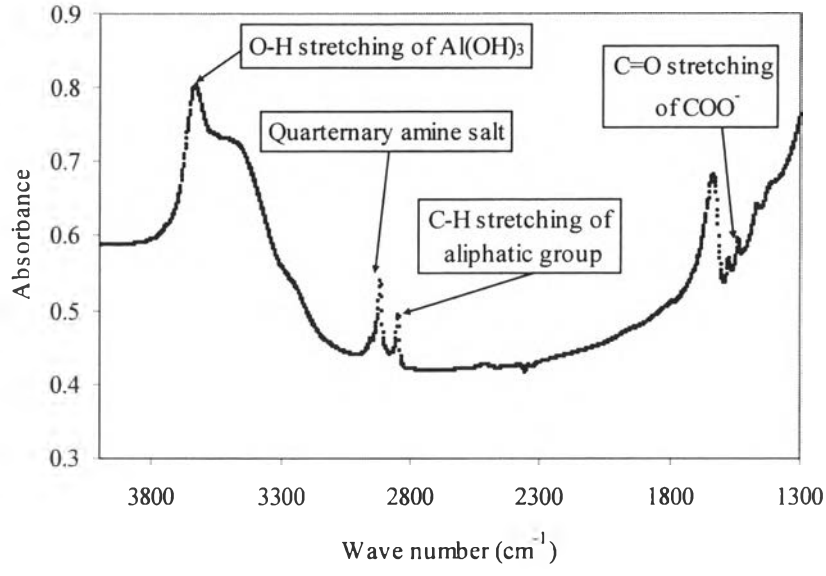

Figure A4 FTIR spectra of SMZ (2:1)

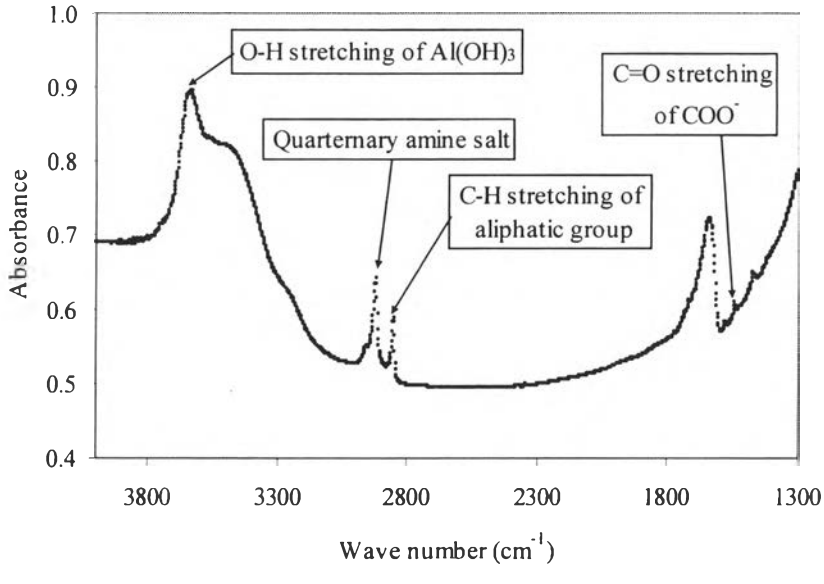

Figure A5 FTIR spectra of SMZ (4:1)

Sample of calculation

Surfactant Adsorption Isotherms

Surfactant adsorption isotherm was constructed by plotting the amount of surfactant adsorbed per gram of clinoptilolite (μmol/g) versus equilibrium concentration of surfactant (μM).

1. To convert the amount of carbon from TOC (ppm) to equilibrium concentration of CTAB (μM)

Equation from TOC: Y = 4.9007X

X = the amount of carbon from TOC (ppm) = 8.287 ppm

Y = equilibrium concentration of CTAB (μM) = 4.9007×8.287

= 40.612 μM

2. Finding CTAB adsorbed concentration (μM)

$[CTAB]_{Adsorbed} = [CTAB]_{Initial}-[CTAB]_{Equilibrium}$

$[CTAB]_{Initial}$ = 50 μM

$[CTAB]_{Equilibrium}$ = 40.612 μM

$[CTAB]_{Adsorbed}$ = 50-40.612 = 9.388 μM

3. To convert adsorption concentration to moles of adsorption

$$\text{Mole} = \frac{\text{Concentration}\times\text{Volume}}{1000}$$

$$\text{Adsorbed (μmol)} = \frac{(\text{Adsorbed (μM)})\times\text{Volume of solution}}{1000}$$

$$\text{Adsorbed (μmol)} = \frac{9.388\times20}{1000} = 0.188 \text{ μmol}$$

4. Finding CTAB adsorbed per gram of clinoptilolite

$$\text{CTAB adsorbed (μmol/g of clinoptilolite)} = \frac{\text{Adsorbed (μmol)}}{\text{the amount of clinoptilolite (g)}}$$

$$= \frac{0.188}{0.2} = 0.939 \text{ μmol/g}$$

Amount of CTAB and palmitic acid adsorbed on clinoptilolite

1. Amount of CTAB in SMZ

the organic carbon contents of SMZ(0:1) = 0.955 wt %

or 1 g of SMZ(0:1) have 0.00955 g of carbon

Convert g of carbon to μmol of CTAB;

$$= \frac{0.00955 \text{ g of carbon}}{1 \text{ g of SMZ}} \times \frac{1 \text{ mol of CTAB}}{228 \text{ g of carbon}} \times \frac{10^6 \text{ μmol}}{1 \text{ mol}}$$

= 41.885 μmol of CTAB/g of SMZ

∴ SMZ (0:1) has CTAB = 41.885 μmol of CTAB/g of SMZ

2. Amount of palmitic acid in SMZ

the organic carbon contents of SMZ(1:1) = 1.481 wt %

or 1 g of SMZ(1:1) have 0.01481 g of carbon

the organic carbon content due to CTAB = 0.00955 g of carbon

∴ the organic carbon content due to palmitic acid = 0.01481-0.00955

= 0.005255 g of carbon

Convert g of carbon to μmol of palmitic acid;

$$= \frac{0.005255 \text{ g of carbon}}{1 \text{ g of SMZ}} \times \frac{1 \text{ mol of palmitic acid}}{192 \text{ g of carbon}} \times \frac{10^6 \text{ μmol}}{1 \text{ mol}}$$

= 27.370 μmol of palmitic acid/g of SMZ

∴ SMZ (1:1) has CTAB 27.370 μmol of CTAB/g of SMZ

and palmitic acid 27.370 μmol of palmitic acid/g of SMZ

Cadmium Adsorption Isotherms

Cadmium adsorption isotherm was constructed by plotting the amount of cadmium adsorbed per gram of SMZ (mg/g) versus equilibrium concentration of cadmium (ppm).

1. To convert absorbance from AAS to $[Cd^{2+}]_{AAS}$ (ppm) of standard solution

Equation from standard solution: $Y = 2.9406X$

X = Absorbance from AAS = 0.583

$Y = [Cd^{2+}]_{AAS}$ (ppm) of standard solution = 2.9406×0.583

= 1.715 ppm

2. To convert $[Cd^{2+}]_{AAS}$ (ppm) of standard solution to real equilibrium Cd^{2+} concentration (ppm)

Equation from calibration curve: $Y = 1.0569X$

$X = [Cd^{2+}]_{AAS}$ (ppm) of standard solution = 1.715 ppm

Y = equilibrium Cd^{2+} concentration (ppm) = $1.0569 \times 1.715 \times 84.33$

(dilution factor = 84.33) = 152.820 ppm

3. Finding Cd^{2+} adsorbed concentration

$[Cd^{2+}]_{Adsorbed} = [Cd^{2+}]_{Initial} - [Cd^{2+}]_{Equilibrium}$

$[Cd^{2+}]_{Initial}$ = 200 ppm

$[Cd^{2+}]_{Equilibrium}$ = 152.820 ppm

$[CTAB]_{Adsorbed} = 200 - 152.820 = 47.180$ ppm

4. To convert adsorption concentration to mass of adsorption

$$\text{Mass} = \frac{\text{Concentration} \times \text{Volume}}{1000}$$

$$\text{Adsorbed (mg)} = \frac{(\text{Adsorbed (ppm)}) \times \text{Volume of solution}}{1000}$$

$$\text{Adsorbed (mg)} = \frac{47.180 \times 20}{1000} = 0.9436\text{ppm}$$

5. Finding Cd^{2+} adsorbed per gram of SMZ

Cd^{2+} adsorbed (mg/g of clinoptilolite) = $\frac{\text{Adsorbed (ppm)}}{\text{the amount of SMZ (g)}}$

$= \frac{0.9436}{0.2} = 4.718$ mg/g

Toluene Adsorption Isotherms

Toluene adsorption isotherm was constructed by plotting the amount of toluene adsorbed per gram of SMZ (μmol/g) versus equilibrium concentration of toluene (μM).

1. To convert area from GC-Headspace to equilibrium concentration of toluene (ppm)

Equation from GC-Headspace: Y = 0.0003X

X = area from GC-Headspace = 1486446.7 ppm

Y = equilibrium concentration of toluene (ppm) = 0.0003×1486446.7

= 445.934 ppm or

= 4839.637 μM

2. Finding toluene adsorbed concentration (ppm)

$[\text{toluene}]_{\text{Adsorbed}} = [\text{toluene}]_{\text{Initial}} - [\text{toluene}]_{\text{Equilibrium}}$

$[\text{toluene}]_{\text{Initial}} = 552.852$ ppm

$[\text{toluene}]_{\text{Equilibrium}} = 445.934$ ppm

$[\text{toluene}]_{\text{Adsorbed}} = 552.852 - 445.934 = 106.918$ ppm

3. To convert adsorption concentration to moles of adsorption

$\text{Mole} = \frac{\text{Concentration (ppm)} \times \text{Volume}}{1000 \times \text{Molecular weight}}$

$\text{Adsorbed (mmol)} = \frac{(\text{Adsorbed (ppm)}) \times \text{Volume of solution}}{1000 \times \text{Molecular weight}}$

$\text{Adsorbed (mmol)} = \frac{106.918 \times 20}{1000 \times 92.142} = 0.0232$ mmol

= 23.207 μmol

4. Finding toluene adsorbed per gram of SMZ

$$\text{toluene adsorbed (}\mu\text{mol/g of SMZ)} = \frac{\text{Adsorbed (}\mu\text{mol)}}{\text{the amount of SMZ (g)}} = \frac{23.207}{0.2} = 116.036\ \mu\text{mol/g}$$

CURRICULUM VITAE

Name: Siriwan Sriwongjanya

Date of Birth: January 28, 1982

Nationality: Thai

University Education:

1998-2002 Bachelor Degree in Chemical Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand.