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APPENDIX

Table A1 Adsorption isotherm of CTAB on clinoptilolite at 30°C

Weight of clinoptilolite = 0.2 g

Volume of CTAB solution = 20 ml

Molecular weight of CTAB = 364.46 g/mol

No	$[CTAB]_{initial}$ (μmol/L)	$[CTAB]_{equilibrium}$ (μmol/L)	Amount of surfactant adsorbed (μmol/g)
1.00	60.34	23.09	3.73
2.00	109.75	22.69	8.71
3.00	219.50	23.91	19.56
4.00	327.74	27.24	30.05
5.00	439.01	64.39	37.46
6.00	532.75	112.34	42.04
7.00	740.58	257.65	48.29
8.00	851.30	326.98	52.43
9.00	1075.73	431.83	64.39
10.00	1297.18	578.32	71.89
11.00	1625.52	804.46	82.11
12.00	2264.31	1428.73	83.56
13.00	3320.03	2477.67	84.24
14.00	4416.20	3599.82	81.64

Table A2 Zeta-Potential data for CTAB adsorption on clinoptilolite

No.	Amount of CTAB adsorbed(μmol/g)	zeta potential (mV)											S.D.
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	Average	
1	0.0	-63.6	-61.9	-61.5	-53.9	-70	-55	-56.7	-54.9	-62.1	-58.1	-59.8	5
2	8.7	-41.4	-44.2	-44	-46.8	-41.5	-40	-37.2	-37.5	-41.9	-37.2	-41.2	3.3
3	19.5	-28.7	-34.6	-39.2	-39.2	-32.8	-42.1	-46.7	-46.2	-46.4	-42	-39.8	6.2
4	30.0	-21.7	-23.1	-21	-21.6	-20	-22	-21.8	-29.3	-26.8	-26.6	-23.4	3.1
5	37.4	-9.2	-5	-4.7	-11.2	-9.7	-11.5	-10	-16.2	-9.6	-11.4	-9.9	3.3
6	48.2	12.3	18.3	11.6	17.3	18.6	17.5	16.7	21	20	14.3	16.7	3.1
7	52.4	34.8	42.9	32.1	31.5	32.5	31.8	33.2	31.4	29.6	31.4	33.1	3.7
8	64.3	38.1	41	42.5	38.1	37.3	30.8	41.7	38.2	42	30.2	38	4.4
9	71.9	44.7	38.5	38.1	34.4	50.5	37.9	54.9	47.4	30.4	29.3	40.6	8.5

Table A3 Adsorption isotherm of lead on clinoptilolite in single-solute systems

Weight of clinoptilolite = 0.2 g

Volume of lead solution = 20 ml

No.	$[Pb^{2+}]_{initial}$ (mM)	$[Pb^{2+}]_{equilibrium}$ (mM)	Amount of Pb^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.003	0.023	0.000
2	0.50	0.008	0.046	0.000
3	1.00	0.023	0.092	0.001
4	1.50	0.062	0.133	0.001
5	2.00	0.123	0.182	0.002
6	2.50	0.217	0.216	0.001
7	3.00	0.388	0.246	0.002
8	4.00	0.761	0.306	0.003
9	5.00	1.417	0.335	0.004

Table A4 Adsorption isotherm of cadmium on clinoptilolite in single-solute systems

Weight of clinoptilolite = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Cd^{2+}]_{initial}$ (mM)	$[Cd^{2+}]_{equilibrium}$ (mM)	Amount of Cd^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.002	0.024	0.000
2	0.50	0.005	0.043	0.000
3	1.00	0.024	0.089	0.000
4	1.50	0.076	0.128	0.001
5	2.00	0.182	0.158	0.001
6	2.50	0.445	0.174	0.003
7	3.00	0.605	0.206	0.000
8	4.00	1.156	0.229	0.003
9	5.00	1.794	0.233	0.002

Table A5 Adsorption isotherm of lead on SMZ in single-metal systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Pb^{2+}]_{initial}$ (mM)	$[Pb^{2+}]_{equilibrium}$ (mM)	Amount of Pb^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.004	0.021	0.000
2	0.50	0.012	0.045	0.000
3	1.00	0.044	0.088	0.000
4	1.50	0.126	0.140	0.000
5	2.00	0.240	0.167	0.001
6	2.50	0.401	0.196	0.000
7	3.00	0.590	0.227	0.001
8	4.00	1.168	0.259	0.001
9	5.00	1.738	0.273	0.003

Table A6 Adsorption isotherm of cadmium on SMZ single-metal systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Cd^{2+}]_{initial}$ (mM)	$[Cd^{2+}]_{equilibrium}$ (mM)	Amount of Cd^{2+}adsorbed (mmol/g)	S.D.
1	0.25	0.003	0.025	0.000
2	0.50	0.003	0.050	0.000
3	1.00	0.018	0.098	0.001
4	1.50	0.067	0.143	0.003
5	2.00	0.160	0.184	0.003
6	2.50	0.302	0.220	0.003
7	3.00	0.374	0.263	0.003
8	4.00	0.979	0.302	0.003
9	5.00	1.750	0.325	0.004

Table A7 Adsorption isotherm of lead on SMZ in mixed-metal systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Pb^{2+}]_{initial}$ (mM)	$[Pb^{2+}]_{equilibrium}$ (mM)	Amount of Pb^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.024	0.022	0.001
2	0.50	0.075	0.043	0.001
3	1.00	0.271	0.073	0.001
4	1.50	0.583	0.092	0.005
5	2.00	0.966	0.103	0.007
6	2.50	1.383	0.112	0.004
7	3.00	1.768	0.123	0.001

Table A8 Adsorption isotherm of cadmium on SMZ in mixed-metal systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Cd^{2+}]_{initial}$ (mM)	$[Cd^{2+}]_{equilibrium}$ (mM)	Amount of Cd^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.037	0.023	0.001
2	0.50	0.071	0.053	0.003
3	1.00	0.162	0.089	0.004
4	1.50	0.501	0.127	0.002
5	2.00	0.930	0.135	0.007
6	2.50	1.334	0.144	0.000
7	3.00	1.868	0.144	0.003

Table A9 Adsorption isotherm of lead on SMZ in mixed-solute systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Pb^{2+}]_{initial}$ (mM)	$[Pb^{2+}]_{equilibrium}$ (mM)	Amount of Pb^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.004	0.023	0.000
2	0.50	0.011	0.046	0.000
3	1.00	0.040	0.090	0.000
4	1.50	0.104	0.131	0.000
5	2.00	0.206	0.167	0.000
6	2.50	0.352	0.207	0.001
7	3.00	0.563	0.226	0.002
8	4.00	1.047	0.272	0.007
9	5.00	1.857	0.278	0.001

Table A10 Adsorption isotherm of cadmium on SMZ in mixed-solute systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Cd^{2+}]_{initial}$ (mM)	$[Cd^{2+}]_{equilibrium}$ (mM)	Amount of Cd^{2+} adsorbed (mmol/g)	S.D.
1	0.25	0.002	0.025	0.000
2	0.50	0.003	0.050	0.000
3	1.00	0.013	0.099	0.000
4	1.50	0.062	0.144	0.001
5	2.00	0.182	0.182	0.001
6	2.50	0.391	0.211	0.005
7	3.00	0.605	0.240	0.000
8	4.00	1.156	0.284	0.003
9	5.00	1.794	0.321	0.002

Table A11 Adsorption isotherm of toluene on SMZ in single-solute systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

No.	$[Toluene]_{initial}$ (μM)	$[Toluene]_{equilibrium}$ (μM)	Amount of toluene Adsorbed(μmol/g)	S.D.
1	0	0	0	0
2	500.00	272.036	22.796	0.345
3	1250.00	658.742	59.126	1.129
4	3000.00	1760.092	123.991	0.000
5	4500.00	2686.448	181.355	6.955
6	5500.00	3334.711	216.529	11.856

Table A12 Adsorption isotherm of toluene on SMZ in mixed-solute systems

Weight of SMZ = 0.2 g

Volume of cadmium solution = 20 ml

	$[Toluene]_{initial}$ (μM)	$[Toluene]_{equilibrium}$ (μM)	Amount of toluene Adsorbed(μmol/g)	S.D.
Toluene(single)	4000	2650.589	134.9411	16.53
Toluene mixed Pb^{2+}	4000	2375.194	162.4806	17.95
Toluene mixed Cd^{2+}	4000	2299.368	170.0632	25.86

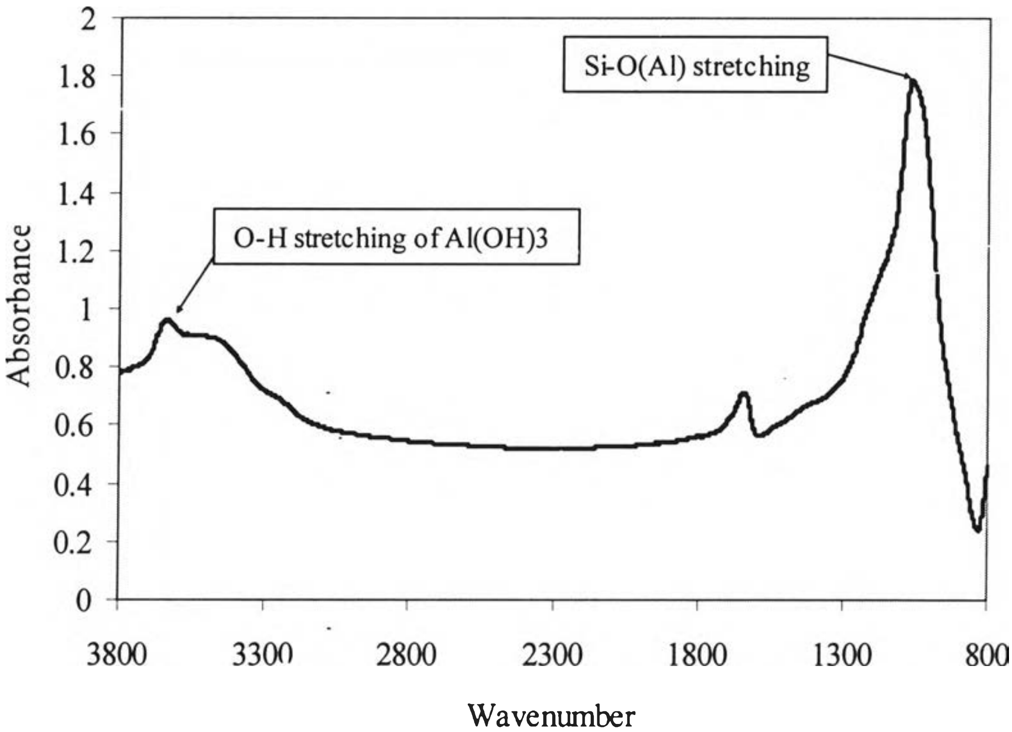

Figure A1 FTIR spectra of clinoptilolite

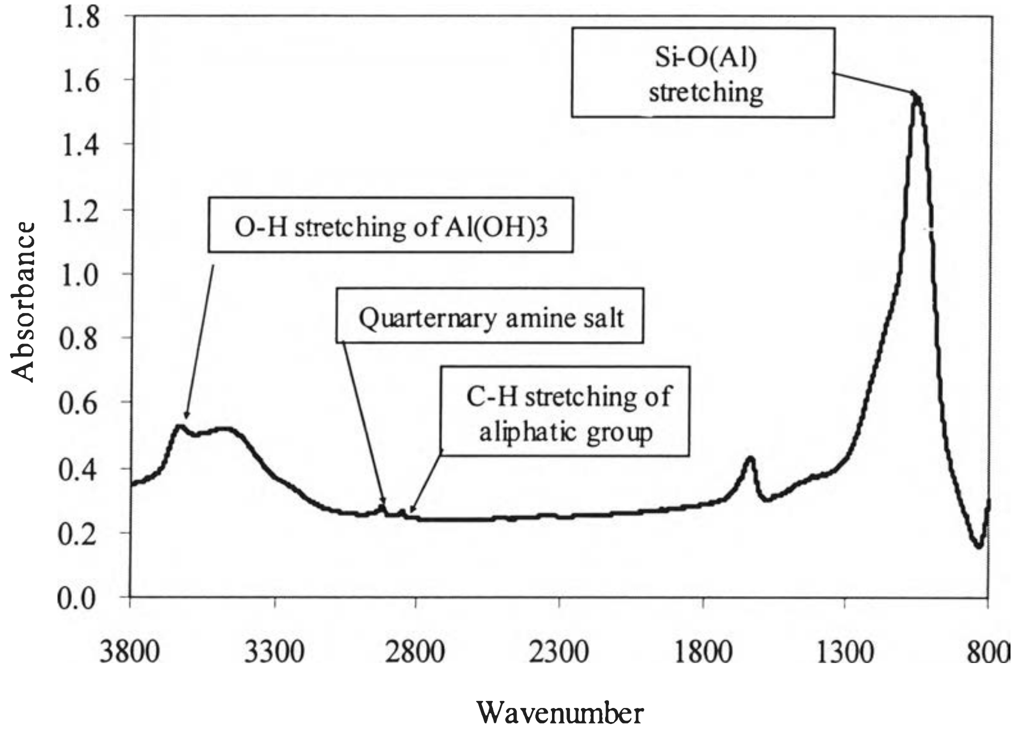

Figure A2 FTIR spectra of CTAB-modified clinoptilolite

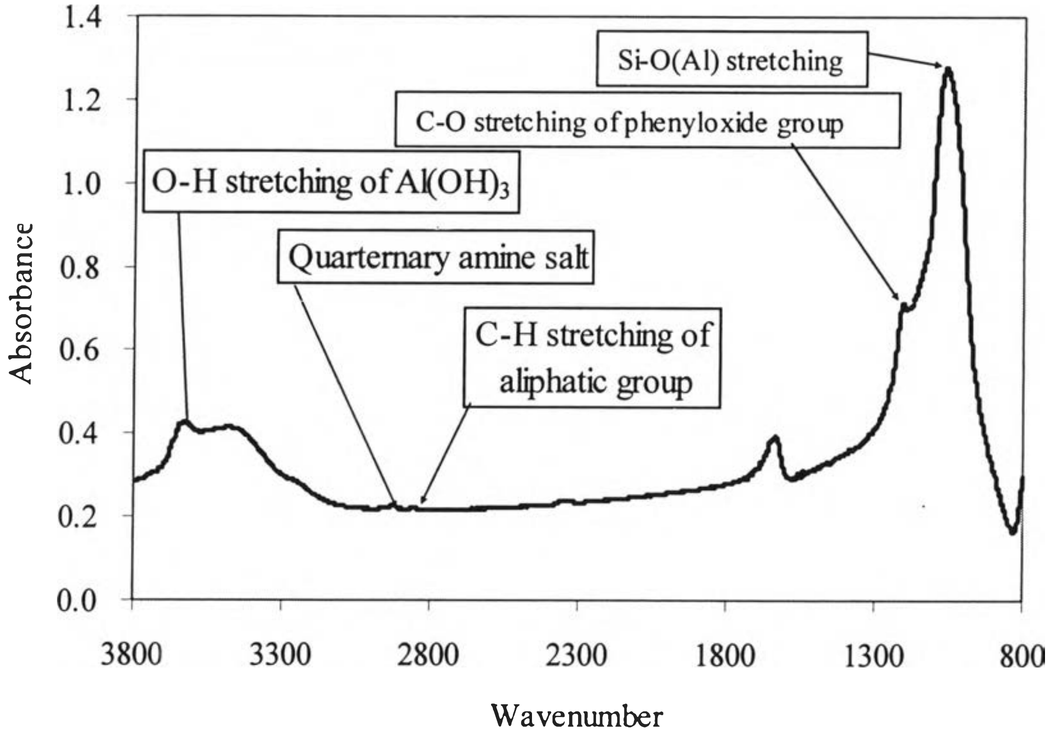

Figure A3 FTIR spectra of SMZ

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 initial and equilibrium concentration of CTAB (μM)

Equation from TOC: Y = 1.5521*X

X = the amount of carbon from TOC (ppm) = 5.327 ppm

Y = the concentration of CTAB (μM) = 1.5521×5.327

= 8.268 ppm

= 8.268 *1000/364.46

= 22.686 μM

2. Finding CTAB adsorbed concentration (μM)

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

$[CTAB]_{Initial}$ = 109.75 μM

$[CTAB]_{Equilibrium}$ = 22.686 μM

$[CTAB]_{Adsorbed}$ = 109.75-22.686 = 87.064 μM

3. To convert adsorption concentration to moles of adsorption

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

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

$$\text{Adsorbed (μmol)} = \frac{87.064\times 20}{1000} = 1.741 \text{ μmol}$$

4. Finding CTAB adsorbed per gram of clinoptilolite

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

$$= \frac{1.741}{0.2} = 8.71 \text{ μmol/g}$$

Heavy metal Adsorption Isotherms

Heavy metal (cadmium and lead) adsorption isotherm was constructed by plotting the amount of cadmium adsorbed per gram of SMZ (mmol/g) versus equilibrium concentration of cadmium (mM).

1. To convert $[Metal]_{AAS}$ (ppm) of standard solution to real equilibrium metal concentration (mM)

For example

$[Cd^{2+}]_{AAS}$ (ppm) of standard solution	= 0.02 ppm
(dilution factor = 12.5)	= 0.02*12.5 = 0.25 ppm
equilibrium Cd^{2+} concentration (mM)	= 0.25/112.41 = 0.0022 mM

2. Finding Cd^{2+} adsorbed concentration

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

$[Cd^{2+}]_{Initial} = 0.25$ mM

$[Cd^{2+}]_{Equilibrium} = 0.0022$ mM

$[CTAB]_{Adsorbed} = 0.25-0.0022 = 0.2478$ mM

4. To convert adsorption concentration to mass of adsorption

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

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

$$\text{Adsorbed (mmol)} = \frac{0.2478\times20}{1000} = 0.004956 \text{ mmol}$$

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

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

$$= \frac{0.004956}{0.2} = 4.718 \text{ mmol/g}$$

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 (μM)

Equation from GC-Headspace: Y = X/1.7415

X = area from GC-Headspace = 478.0

Y = equilibrium concentration of toluene (μM) = 478/1.741

= 274.5 μM

2. Finding toluene adsorbed concentration (ppm)

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

$[toluene]_{Initial}$ = 500 μM

$[toluene]_{Equilibrium}$ = 274.5 μM

$[toluene]_{Adsorbed}$ = 500-274.5 = 225.445 μM

3. To convert adsorption concentration to moles of adsorption

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

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

$$\text{Adsorbed (mmol)} = \frac{225.445 \times 20}{1000} = 4.510\ \mu\text{mol}$$

4. Finding toluene adsorbed per gram of SMZ

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

$$= \frac{4.510}{0.2} = 22.544\ \mu\text{mol/g}$$

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