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APPENDICES

APPENDIX A: Calculation

1. Sample preparation

1.1 Ammonium solution

The ammonium stock solution was firstly prepared, and then the ammonium solutions with desired concentration were prepared from the stock solution. The desired concentration of ammonium solution were 50, 100, 200, 500, 900, 1500, 2000, 2500, and 3000 mg/l.

Preparation of stock solution

The concentration of ammonium stock solution was 5000 mg/l. It was prepared from ammonium chloride (NH_4Cl).

M_w: N = 14, H = 1, Cl = 35.5

NH_4 18 g from NH_4Cl 53.5 g

NH_4 $5000 * 10^{-3}$ g from NH_4Cl 14.8611 g

Therefore NH_4Cl was weight 14.8611 g, then the buffer solution was added to make total volume to 1000 ml.

Preparation of ammonium sample solution

From $$C_1V_1 = C_2V_2 \tag{A1}$$

Where C_1, and C_2 were concentration of stock solution and ammonium sample solution, respectively

V_1, and V_2 were volume of stock solution and ammonium sample solution, respectively

For this system V_2 was 15 ml.

Therefore,

C_2	50	100	200	500	900	1500	2000	2500	3000
V_1	0.15	0.30	0.60	1.50	2.70	4.50	6.00	7.50	9.00

Thus, V_1 ml of the stock solution was diluted with the buffer solution into 15 ml final solution.

1.2 Potassium solution

The potassium stock solution was firstly prepared, and then the potassium solutions with desired concentration were prepared from the stock solution. The desired concentration of potassium solution were 50, 100, 200, 500, 900, 1500, 2000, 2500, and 3000 mg/l.

Preparation of stock solution

The concentration of potassium stock solution was 5000 mg/l. It was prepared from potassium chloride (KCl).

M_w: K = 39.1, Cl = 35.5

K 39.1 g from KCl 74.6 g

K $5000 * 10^{-3}$ g from KCl 9.5396 g

Therefore KCl was weight 9.5396 g, then the buffer solution was added to make total volume to 1000 ml.

Preparation of potassium sample solution

From $C_1V_1 = C_2V_2$

Where C_1, and C_2 were concentration of stock solution and potassium sample solution, respectively

V_1, and V_2 were volume of stock solution and potassium sample solution, respectively

For this system V_2 was 15 ml.

Therefore,

C_2	50	100	200	500	900	1500	2000	2500	3000
V_1	0.15	0.30	0.60	1.50	2.70	4.50	6.00	7.50	9.00

Thus, V_1 ml of the stock solution was diluted with the buffer solution into 15 ml final solution.

2. Buffer preparation

Two buffer solutions were used in this study. The first buffer, acetate buffer, was used to obtain pH 3 and 5, while the second buffer, trisma buffer, provide pH 7 and 9. The buffer strength was fixed at 0.05 M. The volume of each buffer solution was 1000 ml. Both buffer solution were prepared by using this following equation

$$pH = pKa + \log (A/HA) \quad (A2)$$

Where A and HA represented base and weak acid, respectively

2.1 Acetate buffer solution

Acetate buffer with pH 3

pKa of acetate buffer was 4.74.

From equation (A2),

$$pH = pKa + \log (A/HA)$$

$$3 = 4.74 + \log (A/HA)$$

$$A/HA = 0.0182$$

$$M_{b,t} = V_b M_b \quad (A3)$$

Where $M_{b,t}$ was total millimoles of buffer needed

V_b was volume of buffer in ml.

M_b was molar concentration of buffer

$$M_{b,t} = (1000)(0.05) = 50 \text{ mmol total buffer}$$

Then the total mmol was divided into A and HA form

$$50/(1+0.0182) = 49.1063$$

Thus, HA = 49.1063

A = 0.8937

It was meant that there were 49.1063 and 0.8937 mmol of acetate acid and sodium acetate in 1000 ml of buffer solution, respectively.

- Preparation of acetic acid

Molecular weight and density of acetic acid were 60 and 1.05 g/ml, respectively.

Thus, acetic acid used $= 49.1063(10^{-3})(60) = 2.9464$ g

$= 2.9464/1.05 \quad = \quad 2.8061$ ml

- Preparation of sodium acetate

Molecular weight of sodium acetate was 136

Thus, sodium acetate used = $0.8937(10^{-3})(136) = \quad 0.1215$ g

Therefore, 2.8061 ml of acetic acid and 0.1215 g of sodium acetate were mixed together, and then the distilled water was added into the mixture in order to make total volume to 1000 ml.

Acetate buffer with pH 5

Likewise, acetic acid and sodium acetate used were 1.0133 and 4.3884, respectively.

2.2 Trisma buffer solution (tris(hydroxymethyl)aminomethane)

Trisma buffer with pH 7

pKa of trisma buffer was 8.1.

From equation (A2),

$$pH = pKa + \log (A/HA)$$
$$7 = 8.1 + \log (A/HA)$$
$$A/HA = 0.0794$$

From equation (A3),

$$M_{b,t} = (1000)(0.05) = 50 \text{ mmol total buffer}$$

Then the total mmol was divided into A and HA form

$$50/(1+0.0794) = 46.3206$$

Thus, $HA = 46.3206$

$A = 3.6794$

It was meant that there were 46.3206 and 3.6794 mmol of tris (hydroxymethyl)aminomethane hydrochloride (or tris HCl) and tris(hydroxymethyl) aminomethane (or tris base) in 1000 ml of buffer solution, respectively.

- Preparation of tris HCl

Molecular weight tris HCl was 157.6.

Thus, tris HCl used = $46.3206(10^{-3})(157.6)$

= 7.3001 g

- Preparation of tris base

Molecular weight of sodium acetate was 121.1.

Thus, sodium acetate used = $3.6794\ (10^{-3})(121.1)$

= 0.4456 g

Therefore, 7.3001 g of tris HCl and 0.4456 g of tris base were mixed together, and then the distilled water was added into the mixture in order to make total volume to 1000 ml.

Trisma buffer with pH 9

Likewise, tris HCl and tris base used were 0.8811 and 5.3780, respectively.

3. Salt solution preparation

Three salt solutions, which were NaCl, KCl, and $CaCl_2$ were used in the desorption study. The amount of each salt was determined from equation (A4)

$$\text{mol} = g/M_w \tag{A4}$$

where M_w of NaCl, KCl, and $CaCl_2$ were 58.5, 74.6, and 111.08, respectively.

Concentration (mM)	Amount used (g)		
	NaCl	KCl	$CaCl_2$
10	0.585	0.746	1.111
50	2.925	3.730	5.554
100	5.850	7.460	11.108
500	29.250	37.300	55.539
1000	58.500	74.600	111.078

4. Sample Calculation

4.1 Adsorption Part

From the experiments, C_o (mg/l) and C_e (mg/l) which represented the concentration of ions in blank and in sample solution, respectively were obtained.

$$Qa = \frac{(C_o - C_e)^* V}{1000\, W_c} \qquad \text{(A5)}$$

Where V was the volume of liquid in the system (ml) and W_c was the clinoptilolite sample weight (g).

By using Eq. (A5), the amount of ions adsorbed, Qa (mg/g) can be obtained.

4.2 Desorption Part

Following the adsorption cycle, clinoptilolite samples were subjected to the desertion part. From the experiments, C_o (mg/l) and C_e (mg/l) which represented the concentration of ions in blank and in sample solution, respectively were obtained.

$$Qd = \frac{(C_e - C_o)^* V}{1000\, W_c} \qquad \text{(A6)}$$

Where V was the volume of liquid in the system (ml) and W_c was the clinoptilolite sample weight (g).

By using Eq. (A6), the amount of ions desorbed, Qd (mg/g) can be determined.

APPENDIX B: Experimental data

1. Ammonium Adsorption and Desorption

1.1. Ammonium Adsorption Isotherm

Table B.1 Experimental data of ammonium adsorption isotherm of natural clinoptilolite at pH 3 and initial concentration of 50, 100, 200, 500, 900, 1500, and3000 mg/l

sample	W_c	C_e(mg/l)	Qa(mg/g)	pH
50(1)	0.3004	3.62	1.67	3.75
50(2)	0.3005	3.64	1.67	3.75
100(1)	0.3001	7.81	3.58	3.72
100(2)	0.3005	7.91	3.57	3.75
200(1)	0.3001	25.00	6.45	3.75
200(2)	0.2998	25.10	6.45	3.75
500(1)	0.3002	144.00	11.34	3.69
500(2)	0.2998	145.00	11.31	3.67
900(1)	0.3000	362.00	16.70	3.68
900(2)	0.2997	374.00	16.12	3.66
1500(1)	0.2999	756.00	16.21	3.59
1500(2)	0.3006	772.00	15.37	3.60
3000(1)	0.3006	1140.00	13.47	3.58
3000(2)	0.2996	1170.00	12.02	3.60

Table B.2 Experimental data of ammonium adsorption isotherm for blank condition at pH 3 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	50	100	200	500	900	1500	3000
C_o(mg/l)	37.10	79.40	154.00	371.00	696.00	1080.00	1410.00
pH	3.16	3.15	3.15	3.16	3.15	3.17	3.15

Table B.3 Experimental data of ammonium adsorption isotherm of natural clinoptilolite at pH 5 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	W_c	C_e(mg/l)	Qa(mg/g)	pH
50(1)	0.2998	8.88	1.37	5.04
50(2)	0.3002	15.60	1.03	5.03
100(1)	0.3002	19.00	2.95	5.03
100(2)	0.3001	17.70	3.02	5.04
200(1)	0.3002	44.90	5.15	5.05
200(2)	0.3000	41.70	5.32	5.03
500(1)	0.3001	167.00	10.45	5.04
500(2)	0.3004	165.00	10.54	4.99
900(1)	0.3001	406.00	13.10	5.02
900(2)	0.3000	406.00	13.10	4.85
1500(1)	0.3002	788.00	17.59	5.02
1500(1)	0.2999	794.00	17.31	5.00
3000(1)	0.2998	1090.00	17.46	4.98
3000(2)	0.3001	1110.00	16.44	4.97

Table B.4 Experimental data of ammonium adsorption isotherm for blank condition at pH 5 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	50	100	200	500	900	1500	3000
C_o(mg/l)	36.20	78.10	148.00	376.00	668.00	1140.00	1439.00
pH	4.43	4.44	4.44	4.44	4.45	4.45	4.44

Table B.5 Experimental data of ammonium adsorption isotherm of natural clinoptilolite at pH 7 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	W_c	C_e(mg/l)	Qa(mg/g)	pH
50(1)	0.2994	3.88	1.97	7.44
50(2)	0.3004	3.85	1.96	7.42
100(1)	0.3000	8.91	4.20	7.45
100(2)	0.3002	8.45	4.22	7.43
200(1)	0.3003	28.80	7.20	7.42
200(2)	0.2998	27.80	7.26	7.45
500(1)	0.2994	155.00	11.52	7.41
500(2)	0.2995	160.00	11.27	7.41
900(1)	0.2999	411.00	14.15	7.42
900(2)	0.3003	410.00	14.19	7.37
1500(1)	0.3003	841.00	17.93	7.36
1500(1)	0.3005	855.00	17.22	7.39
3000(1)	0.2996	1210.00	18.52	7.35
3000(2)	0.2998	1210.00	18.51	7.38

Table B.6 Experimental data of ammonium adsorption isotherm for blank condition at pH 7 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	50	100	200	500	900	1500	3000
C_o(mg/l)	43.20	92.90	173.00	385.00	694.00	1200.00	1580.00
pH	7.12	7.12	7.10	7.09	7.07	7.03	7.03

Table B.7 Experimental data of ammonium adsorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	W_c	C_e(mg/l)	Qa(mg/g)	pH
50(1)	0.3006	2.76	1.67	3.75
50(2)	0.3003	2.55	1.68	3.75
100(1)	0.3000	5.16	3.65	3.72
100(2)	0.3002	5.24	3.64	3.75
200(1)	0.3007	16.00	6.58	3.75
200(2)	0.3001	15.80	6.61	3.75
500(1)	0.3001	107.00	13.45	3.69
500(2)	0.3002	100.00	13.79	3.67
900(2)	0.2998	283.00	19.26	3.66
1500(1)	0.3007	631.00	56.87	3.59
1500(2)	0.3006	569.00	56.89	3.60
2000(1)	0.3001	855.00	29.19	3.58
2000(2)	0.3006	870.00	28.39	3.60

Table B.8 Experimental data of ammonium adsorption isotherm for blank condition at pH 9 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	50	100	200	500	900	1500	3000
C_o(mg/l)	36.20	78.10	148.00	376.00	668.00	1140.00	1439.00
pH	9.17	9.19	9.11	8.96	8.73	8.72	8.64

1.2. Kinetics of Ammonium Adsorption

Table B.9 Experimental data of kinetics of ammonium adsorption of natural clinoptilolite at pH 3 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	639
1	611
2	593
3	579
4	565
5	558
6	547
7	537
8	535
9	533
10	527
11	524
12	522
13	516
14	514
15	512
16	509
17	507
18	505
19	503
20	501

t	C_t (mg/l)
21	499
22	497
23	497
24	495
25	493
26	493
27	491
28	491
29	489
30	489
32	485
34	483
36	483
38	483
40	481
42	479
44	479
46	477
48	477
50	475
52	475

t	C_t (mg/l)
54	475
56	475
58	475
60	473
65	473
70	473
75	471
80	471
85	473
100	469
110	469
120	470
140	471
160	472
180	473
250	474
300	475
350	476
400	477
500	478

Table B.10 Experimental data of kinetics of ammonium adsorption of natural clinoptilolite at pH 5 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	660
1	584
2	572
3	558
4	544
5	535
6	529
7	520
8	516
9	512
10	509
11	505
12	501
13	499
14	497
15	495
16	493
17	491
18	489
19	489

t	C_t (mg/l)
20	487
21	485
22	483
23	481
24	481
25	479
26	477
27	477
28	475
29	473
30	473
32	471
34	469
36	467
38	464
40	464
42	462
44	460
48	456
50	456

t	C_t (mg/l)
55	452
60	450
65	447
70	445
75	443
80	443
90	439
100	436
110	434
120	432
140	436
160	436
180	436
200	437
250	438
300	439
400	440
500	441
600	442

Table B.11 Experimental data of kinetics of ammonium adsorption of natural clinoptilolite at pH 7 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	688
1	581
2	512
3	505
4	507
5	512
6	507
7	509
9	509
10	507
11	505
12	503
13	499
14	499
15	495
16	493
17	491

t	C_t (mg/l)
18	489
19	487
20	485
22	483
25	481
30	479
32	479
34	477
36	477
38	477
40	477
45	475
50	475
55	475
60	473
70	473
80	475

t	C_t (mg/l)
90	475
100	475
120	456
140	422
190	435
204	434
257	425
295	430
301	434
316	439
328	443
344	447
374	439
379	450
388	447
411	441

Table B.12 Experimental data of kinetics of ammonium adsorption of natural clinoptilolite at pH 9 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	544
1	427
2	396
3	382
4	367
5	356
7	350
9	348
10	345
11	341
12	338
13	335
14	332
15	328
16	324

t	C_t (mg/l)
17	321
18	319
19	318
20	315
22	311
24	306
26	302
28	300
30	296
32	294
34	291
36	290
38	288
40	287
45	283

t	C_t (mg/l)
50	281
55	277
60	275
70	274
80	270
90	268
100	268
110	267
228	277
283	272
346	277
411	285
419	304

1.3. Ammonium Desorption Isotherm

Table B.13 Experimental data of ammonium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, and 900 mg/l with NaCl 10 mM

sample	adsorption part			desorption part	
	Wc	Ce	Qa	Ce	Qd
50(b)	-	36.2	-	-	-
50	0.3006	2.76	1.669	1.21	0.060
100(b)	-	78.1	-	-	-
100	0.3000	5.16	3.647	2.10	0.105
200(b)	-	148	-	-	-
200	0.3007	16.00	6.585	2.83	0.141
500(b)	-	376	-	-	-
500	0.3001	107.00	13.446	9.57	0.478
900(b)	-	668	-	-	-
900	0.3009	283.00	19.192	15.00	0.748
1500(b)	-	1140	-	-	-
1500	0.3007	631.00	25.391	18.57	0.926

Table B.14 Experimental data of ammonium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, and 900 mg/l with NaCl 50 mM

sample	adsorption part			desorption part	
	Wc	Ce	Qa	Ce	Qd
50(b)	-	36.20	-	-	-
50	0.3003	2.55	1.681	5.02	0.251
100(b)	-	78.10	-	-	-
100	0.3002	5.24	3.641	10.00	0.500
200(b)	-	148.00	-	-	-
200	0.3001	15.80	6.608	15.00	0.750
500(b)	-	376.00	-	-	-
500	0.3002	100.00	13.791	35.00	1.749
900(b)	-	668.00	-	-	-
900	0.2998	283.00	19.263	55.00	2.752
1500(b)	-	1140.00	-	-	-
1500	0.3006	569.00	28.493	20.00	0.998

Table B.15 Experimental data of ammonium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, and 900 mg/l with NaCl 100 mM

sample	adsorption part			desorption part	
	Wc	Ce	Qa	Ce	Qd
50(b)	-	36.20	-	-	-
50	0.2998	8.88	1.367	7.94	0.397
100(b)	-	78.10	-	-	-
100	0.3002	19.00	2.953	13.70	0.685
200(b)	-	148.00	-	-	-
200	0.3002	44.90	5.152	27.70	1.384
500(b)	-	376.00	-	-	-
500	0.3001	167.00	10.447	63.90	3.194
900(b)	-	668.00	-	-	-
900	0.3001	406.00	13.096	113.00	5.648
1500(b)	-	1140.00	-	-	-
1500	0.3002	788.00	17.588	221.00	11.043

Table B.16 Experimental data of ammonium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, and 1500 mg/l with KCl 100 mM

sample	adsorption part			desorption part	
	Wc	Ce	Qa	Ce	Qd
900 (b)	-	794	-	-	-
900 (1)	0.3001	700	4.698	1620.00	12.99
900 (2)	0.2998	694	5.003	1660.00	15.00
1500 (b)	-	1570	-	-	-
1500 (1)	0.2999	1439	6.552	1800.00	21.81
1500 (2)	0.3002	1370	9.993	2000.00	29.60

Table B.17 Experimental data of ammonium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, and 1500 mg/l with NaCl 100 mM

sample	adsorption part			desorption part	
	Wc	Ce	Qa	Ce	Qd
50 (b)	-	36.2	-	-	-
50	0.2998	8.88	1.367	7.94	0.306
100 (b)	-	78.1	-	-	-
100	0.3002	19.00	2.953	13.70	0.594
200 (b)	-	148	-	-	-
200	0.3002	44.90	5.152	27.70	1.293
500 (b)	-	376	-	-	-
500	0.3001	167.00	10.447	63.90	3.103
900 (b)	-	668	-	-	-
900	0.3002	406.00	13.096	113.00	5.557
1500 (b)	-	1140	-	-	-
1500	0.2998	788.00	17.588	221.00	10.952

Table B.18 Experimental data of ammonium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, and 1500 mg/l with $CaCl_2$ 100 mM

sample	adsorption part			desorption part	
	Wc	Ce	Qa	Ce	Qd
50 (b)	-	36.20	-	-	-
50	0.3002	15.60	1.029	17.90	0.82
100 (b)	-	78.10	-	-	-
100	0.3001	17.70	3.019	24.80	1.16
200 (b)	-	148.00	-	-	-
200	0.3000	41.70	5.315	45.00	2.17
500 (b)	-	376.00	-	-	-
500	0.3004	165.00	10.536	101.00	4.97
900 (b)	-	668.00	-	-	-
900	0.3000	406.00	13.100	172.00	8.52
1500 (b)	-	1140.00	-	-	-
1500	0.2999	794.00	17.306	288.00	14.33

1.4. Kinetics of Ammonium Desorption

Table B.19 Experimental data of kinetics of ammonium desorption of natural clinoptilolite at pH 9 and Qa = 28.06 mg/l

t	C_t (mg/l)	t	C_t (mg/l)	t	C_t (mg/l)
0	7	15	671	57	824
1	415	16	685	60	835
2	471	18	699	70	852
3	505	19	705	80	862
4	533	20	711	90	860
5	553	22	720	100	866
6	572	24	732	171	821
7	588	26	738	217	814
8	606	28	744	263	818
9	618	30	753	326	811
10	634	36	769	390	821
11	641	40	781		
12	652	45	794		
14	677	50	811		

2. Potassium Adsorption and Desorption

2.1. Potassium Adsorption Isotherm

Table B.20 Experimental data of potassium adsorption isotherm of natural clinoptilolite at pH 3 and initial concentration of 50, 100, 200, 500, 900, 1500, 2000, 2500, and 3000 mg/l

sample	W_c	C_e(mg/l)	Q_a(mg/g)	pH
50(1)	0.2993	26.70	0.80	3.72
50(2)	0.3007	27.30	0.77	3.65
100(1)	0.3007	32.00	2.89	3.64
100(2)	0.3001	33.10	2.84	3.66
200(1)	0.3005	48.10	7.13	3.66
200(2)	0.3000	48.10	7.15	3.69
500(1)	0.2993	131.00	16.59	3.61
500(2)	0.3002	131.00	16.54	3.64
900(1)	0.2997	336.00	25.28	3.66
900(2)	0.2998	332.00	25.47	3.66
1500(1)	0.3005	791.00	25.41	3.69
1500(2)	0.2997	785.00	25.78	3.61
2000(1)	0.2994	1200	32.57	3.64
2500(2)	0.3003	1580	36.46	3.66
3000(1)	0.2996	2100.00	33.04	3.61
3000(2)	0.3005	2080.00	33.94	3.64

Table B.21 Experimental data of potassium adsorption isotherm for blank condition at pH 3 and initial concentration of 50, 100, 200, 500, 900, 1500, 2000, 2500, and 3000 mg/l

sample	50	100	200	500	900	1500	2000	2500	3000
C_o(mg/l)	42.7	89.9	191.0	462	841	1300	1850	2310	2760
pH	3.16	3.15	3.14	3.14	3.14	3.16	3.14	3.15	3.16

Table B.22 Experimental data of potassium adsorption isotherm of natural clinoptilolite at pH 5 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	w_c	C_e(mg/l)	Q_a(mg/g)	pH
50(1)	0.3007	13.7	1.79	5.02
50(2)	0.3006	8.1	2.06	5.05
100(1)	0.3007	17.5	3.69	5.01
100(2)	0.3009	10.2	4.05	5.01
200(1)	0.3004	18.7	8.80	5.01
200(2)	0.3006	19.3	8.77	5.02
500(1)	0.3000	95.6	19.37	5.02
500(2)	0.3007	81.1	20.05	5.01
900(1)	0.2997	296.0	28.33	5.01
900(2)	0.3008	283.0	28.87	5.02
1500(1)	0.3005	744.0	33.24	5.02
1500(2)	0.3007	747.0	33.07	5.02
3000(1)	0.3002	2090.0	43.97	5.02
3000(2)	0.3008	2070.0	44.88	5.02

Table B.23 Experimental data of potassium adsorption isotherm for blank condition at pH 5 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	50	100	200	500	900	1500	3000
C_o(mg/l)	49.5	91.4	195.0	483	862	1410	2970
pH	4.88	4.88	4.88	4.87	4.87	4.87	4.87

Table B.24 Experimental data of potassium adsorption isotherm of natural clinoptilolite at pH 7 and initial concentration of 50, 100, 200, 500, 900, 1500, 2000, 2500, and 3000 mg/l

sample	w_c	C_e(mg/l)	Q_a(mg/g)	pH
50(1)	0.3008	6.74	0.51	7.29
50(2)	0.3006	5.91	0.55	7.30
100(1)	0.3000	10.10	4.50	7.35
100(2)	0.3008	9.80	4.50	7.33
200(1)	0.2995	20.10	10.51	7.33
200(2)	0.2997	21.00	10.46	7.35
500(1)	0.2993	83.10	24.25	7.30
500(2)	0.3006	82.80	24.16	7.34
900(1)	0.3001	312.00	35.89	7.32
900(2)	0.2998	291.00	36.97	7.30
1500(1)	0.3007	821.00	43.35	7.28
1500(2)	0.3003	811.00	43.91	7.30
2000(1)	0.3005	1270	52.91	7.29
2500(2)	0.3003	1640	61.89	7.27
3000(1)	0.3003	2180.00	61.94	7.28
3000(2)	0.2995	2220.00	60.10	7.28

Table B.25 Experimental data of potassium adsorption isotherm for blank condition at pH 7 and initial concentration of 50, 100, 200, 500, 900, 1500, 2000, 2500, and 3000 mg/l

sample	50	100	200	500	900	1500	2000	2500	3000
C_o(mg/l)	16.9	100.0	230	567	1030	1690	2330	2879	3420
pH	6.97	6.96	6.98	6.98	6.98	7.02	7.02	7.03	7.03

Table B.26 Experimental data of potassium adsorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	w_c	C_e(mg/l)	Q_a(mg/g)	pH
50(1)	0.2999	4.47	1.59	9.17
50(2)	0.3001	4.43	1.59	9.19
100(1)	0.3009	14.50	2.79	9.16
100(2)	0.2995	5.58	3.25	9.17
200(1)	0.2995	12.00	8.26	9.16
200(2)	0.3004	11.40	8.27	9.16
500(1)	0.3007	56.20	19.10	9.13
500(2)	0.2991	57.20	19.15	9.12
900(1)	0.3006	233.00	27.20	9.10
900(2)	0.3007	234.00	27.14	9.10
1500(1)	0.3000	696.00	25.60	9.10
1500(2)	0.3000	691.00	25.85	9.09
3000(1)	0.3008	2020.00	24.38	9.08
3000(2)	0.3006	2040.00	23.40	9.09

Table B.27 Experimental data of potassium adsorption isotherm for blank condition at pH 9 and initial concentration of 50, 100, 200, 500, 900, 1500, and 3000 mg/l

sample	50	100	200	500	900	1500	3000
C_o(mg/l)	36.2	70.5	177.0	439	778	1208	2509
pH	9.12	9.10	9.11	9.10	9.13	9.13	9.11

2.2. Kinetics of Potassium Adsorption

Table B.28 Experimental data of kinetics of potassium adsorption of natural clinoptilolite at pH 3 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	845
1	688
2	652
3	634
4	621
5	608
6	601
7	593
8	586
9	581
10	574
11	569
12	565
13	562
14	558
15	555
16	553
17	551
18	549
19	549

t	C_t (mg/l)
20	549
21	546
22	544
24	540
25	537
26	537
28	531
30	527
32	520
34	518
36	514
38	512
40	509
45	505
48	501
50	499
57	493
60	491
65	489
70	489

t	C_t (mg/l)
80	487
90	483
94	485
139	493
145	493
162	489
161	489
180	487
204	485
211	483
232	479
240	479
270	477
300	479
330	465
360	473
390	477
394	479

Table B.29 Experimental data of kinetics of potassium adsorption of natural clinoptilolite at pH 5 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	921
1	769
2	735
3	711
4	699
5	685
6	677
7	668
8	663
9	655
10	652
11	649
12	644
13	639
14	634
15	631
16	626
17	623
18	621
19	618
20	613
22	611
24	603
26	598
28	574
30	574
32	569
34	567
39	560
45	553
50	551
60	544
70	537
85	533
144	527
268	520
291	520
444	529

Table B.30 Experimental data of kinetics of potassium adsorption of natural clinoptilolite at pH 7 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	1070
1	845
2	814
3	798
4	785
5	772
6	762
7	756
8	747
9	738
10	729
11	723
12	717
13	711
14	705
15	702
16	696
17	691
18	688
19	685
20	682
21	679
22	677
23	671

t	C_t (mg/l)
24	671
25	666
26	663
27	660
28	655
29	652
30	649
32	644
34	639
36	634

t	C_t (mg/l)
38	628
40	626
45	618
50	613
55	611
60	608
65	606
70	603
80	601
90	598

t	C_t (mg/l)
100	596
141	591
150	588
184	586
193	586
229	586
241	586
300	588

Table B.31 Experimental data of kinetics of potassium adsorption of natural clinoptilolite at pH 9 and initial concentration of 900 mg/l

t	C_t (mg/l)
0	544
1	427
2	396
3	382
4	367
5	356
7	350
9	348
10	345
11	341
12	338
13	335
14	332
15	328
16	324

t	C_t (mg/l)
17	321
18	319
19	318
20	315
22	311
24	306
26	302
28	300
30	296
32	294
34	291
36	290
38	288
40	287
45	283

t	C_t (mg/l)
50	281
55	277
60	275
70	274
80	270
90	268
100	268
110	267
228	277
283	272
346	277
411	285
419	304

2.3. Potassium Desorption Isotherm

Table B.32 Experimental data of potassium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 100, 200, 500, 900, and 1500 mg/l with NaCl 100 mM

sample	adsorption part			desorption part	
	W_c	Ce	Qa	Ce	Qd
100 (b)	-	100	-	-	-
100	0.3000	10.1	4.495	57.40	2.870
200 (b)	-	230	-	-	-
200	0.2995	20.1	10.513	88.00	4.407
500 (b)	-	567	-	-	-
500	0.2993	83.1	24.252	182.00	9.121
900 (b)	-	1030	-	-	-
900	0.3001	312	35.888	282.00	14.095
1500 (b)	-	1690	-	-	-
1500	0.3007	821	43.349	495.00	24.692

Table B.33 Experimental data of potassium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 100, 200, 500, 900, and 1500 mg/l with NaCl 500 mM

sample	adsorption part			desorption part	
	W_c	Ce	Qa	Ce	Qd
100 (b)	-	100	-	-	-
100	0.3008	9.8	4.498	210	1.995
200 (b)	-	230	-	-	-
200	0.2997	21	10.460	262	4.605
500 (b)	-	567	-	-	-
500	0.3006	82.8	24.162	406	11.776
900 (b)	-	1030	-	-	-
900	0.2998	291	36.975	579	20.464
1500 (b)	-	1690	-	-	-
1500	0.3003	811	43.906	775	30.220

Table B.34 Experimental data of potassium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, and 3000 mg/l with NaCl 1000 mM

sample	adsorption part			desorption part	
	W_c	Ce	Qa	Ce	Qd
50 (b)	-	49.50	-	-	-
50	0.3007	13.70	1.786	23.38	1.166
100 (b)	-	91.40	-	-	-
100	0.3007	17.50	3.686	63.38	3.162
200 (b)	-	195.00	-	-	-
200	0.3004	18.70	8.803	149.38	7.459
500 (b)	-	483.00	-	-	-
500	0.3000	95.60	19.370	360.38	18.019
900 (b)	-	862.00	-	-	-
900	0.2997	296.00	28.328	559.38	27.997
3000(b)	-	2970	-	-	-
3000	0.3002	2090.00	43.971	798.00	39.873

Table B.35 Experimental data of potassium desorption isotherm of natural clinoptilolite at pH 9 and initial concentration of 50, 100, 200, 500, 900, and 3000 mg/l with $CaCl_2$ 1000 mM

sample	adsorption part			desorption part	
	W_c	Ce	Qa	Ce	Qd
50 (b)	-	49.50	-	-	-
50	0.3006	8.14	2.064	20.00	0.998
100 (b)	-	91.40	-	-	-
100	0.3009	10.20	4.048	66.00	3.290
200 (b)	-	195.00	-	-	-
200	0.3006	19.30	8.767	132.00	6.587
500 (b)	-	483.00	-	-	-
500	0.3007	81.10	20.048	402.00	20.053
900 (b)	-	862.00	-	-	-
900	0.3008	283.00	28.873	562.00	28.025
3000(b)	-	2970	-	-	-
3000	0.3008	2070.00	44.880	868.00	43.285

2.4. Kinetics of Potassium Desorption

Table B.36 Experimental data of kinetics of potassium desorption of natural clinoptilolite at pH 9 and Qa = 46.97 mg/g

t	C_t (mg/l)
0	3
1	1000
2	1090
3	1150
4	1180
5	1210

t	C_t (mg/l)
6	1230
7	1240
8	1250
9	1260
10	1260
11	1270

t	C_t (mg/l)
12	1270
13	1280
14	1289
15	1300
16	1300
17	1310

t	C_t (mg/l)
18	1310
19	1320
20	1320
21	1330
24	1350
26	1360
28	1370
30	1370
32	1380
34	1400
36	1400

t	C_t (mg/l)
38	1410
40	1420
45	1439
50	1460
55	1480
60	1480
70	1520
80	1550
90	1570
100	1580
110	1600

t	C_t (mg/l)
126	1620
190	1700
221	1720
240	1750
300	1810
423	1800
485	1840
513	1860
541	1830
554	1780

3. Release of Preloaded-Mixed Ions Clinoptilolite

Table B.37 Experimental data of NH_4^+ loading at pH 7 using ammonium ion selective electrode (ISE)

sample	W_c	Ce	Qa
blank	-	5890	-
1	0.3500	5090.00	39.98
2	0.3503	4670.00	60.92

Table B.38 Experimental data of K^+ loading at pH 7 using Atomic Adsorption Spectrophotometer (AAS) with 5000 times dilution

sample	Abs	C_{aas}	C_{gp}	Ce	Qa
blank	0.215	0.38	0.378	1895	-
1	0.133	0.24	0.239	1195	35.01
2	0.174	0.31	0.308	1545	17.49

Table B.39 Experimental data for calibration of K^+ loading at pH 7 using Atomic Adsorption Spectrophotometer (AAS)

Ce	Abs
0.2	0.111
0.5	0.286
1	0.579

Figure B.1 Calibration curve of K^+ loading at pH 7 using Atomic Adsorption Spectrophotometer (AAS)

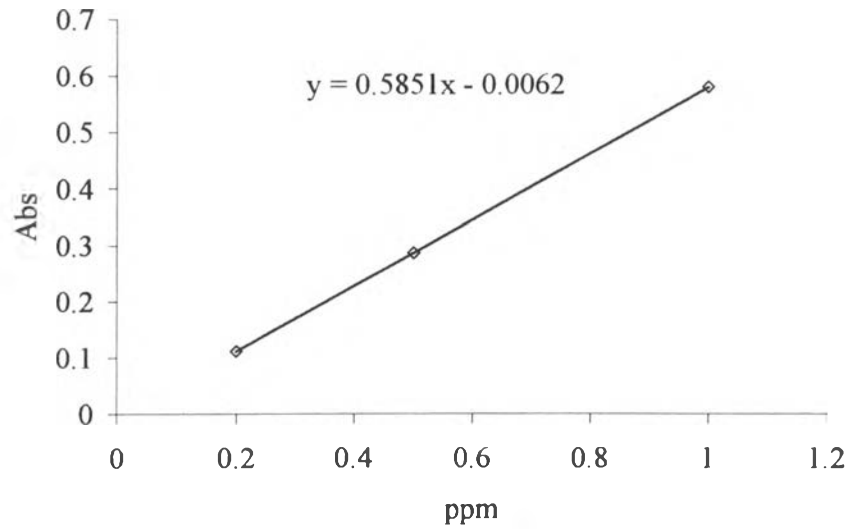

Table B.40 Experimental data of NH_4^+ and K^+ release at pH 7 using ammonium and potassium ion selective electrode (ISE)

sample	W_c	Qa	Ce	Qd	Qr
1	0.2862	39.98	450.00	23.58	16.39
2	0.2765	60.92	740.00	40.15	20.77

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