J. King Saud Univ., Vol. 6, *Science* (1), pp. 81–96 (A.H. 1414/1994).

Sorption of Thorium by Some Saudi Natural Clays, Synthetic Resins and Metal Oxides

A.A. Al-Suhybani
Chemistry Department, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia

(Received 8 May 1993; accepted for publication 26 September 1993)

Abstract. The sorption of thorium, from aqueous solutions, by some local natural clays was found to be very fast reaction following, mainly, film diffusion mechanism. The equilibrium was attained within 20 minutes reaction time and it depends, mainly on the nature of the clay and the pH of the solution. Heat and acid treatments of the clays cause some decrease in the uptake. For comparison purposes, some synthetic exchangers and metal oxides were used as sorbents for Th^{4+}.

Introduction

Thorium being a source material for nuclear energy was and still, like uranium, the subject of vast scientific and technological research.

It is well established that Th^{4+} tends strongly to high hydration number [1]. The hydrolysis of thorium ion is rather less than other tetrapositive ions [2]. Thus Hietanen studied the hydrolysis of Th^{4+} in 1M ClO_4^- solutions and concluded that thorium forms series of complexes of the type $[MO(OH)M]_n$ where n varies between one and six [3].

As far as the complexation of thorium with nitrate ions, it was reported [4] that the stability constant of the mononitrate complex ion $(ThNO_3)^{3+}$ was found to be ~ 4.7 at ionic strength of 0.5. The stability constants of the nitrate complex ions of Th by extraction with tributyl phosphate from HNO_3 solutions at the ionic strength of 2 were determined to be ~ 6, 13, 10 and 5.5 respectively for the complexes $(ThNO_3)^{3+}$, $Th(NO_3)_2^{2+}$, $Th(NO_3)_3^+$, and $Th(NO_3)_4$ [5].

Concerning the precipitation of thorium species, it was indicated conductimetrically that the products of hydrolysis of Th begin to precipitate at pH ~ 3.7 [6].

The ion exchange behavior of thorium ions has been studied extensively. Thus Milkey [7] has studied the adsorption of Th^{4+} on surfaces of glass and polyethylene and found that hydrolysis of Th^{4+} plays an important rule in adsorption. Beran [8] studied the sorption of hydrolysis complexes of Th with some cationic exchangers and found that only the hydrolysis complexes $Th(OH)^{3+}$, $Th(OH)_2^{2+}$, $Th(OH)_3^{+}$ and $Th(OH)_4$ are formed. Others [9] found that the sorption of hydrolysis complexes of Th by ion exchange resins is accompanied by an increase in stability of bond between the ions and the resin. This was attributed to the increase in the charge of the hydrolyzed ions $Th[(OH)_3Th]_n^{(4+n)+}$

The sorption of thorium by many inorganic phosphates and hydrous oxides have been carried out [10-14]. In a preliminary work, Al-Suhybani *et al.* [15, 16] and Hallaba *et al.* [17] have investigated some natural clays as sorbent for thorium. They found that the uptake capacity of these clays was found to be 10-17 meq Th/100 g clay. This uptake was found to increase in the sequence fine > medium > coarse.

Experimental

A very sensitive spectrophotometric technique for determination of thorium has been carried out using Arsenazo-1 as complexing agent. This reagent is benzene-2-arsonic acid-1-azo-7-1,8-dihydroxynaphthalene-3-6-disulphonic acid. It reacts with Th^{4+} to form a complex where the ratio of metal: ligand is 1:2 [18]. The maximum absorption of the complex is at 575 nm while that of the ligand is at 495 nm. The absorption spectra of both complex and ligand depend on pH, where the maximum for the complex is at pH=2. At higher pH values the complex is not stable but at pH < 2, it is stable for at least few days.

Solutions were prepared by adding the appropriate volumes of thorium nitrate and arsenazo solutions into 25 ml volumetric flask and adjusting the pH to 2 by adding dilute nitric acid solutions. 2 grams of the crude clay were added to 20 ml of thorium nitrate solution in a plastic container with continuous shaking. The uptake was followed by measuring the absorption of the complex formed by clear solution, obtained after centrifugation of the mixture at different time intervals using either Beckman Spectrophotometer Model 35, or LKB 4050 spectrophotometer.

The percent uptake was calculated according to the following:

$$\% \text{ Uptake} = \frac{(A_0 - A_t)}{A_0} \times 100$$

where A_O is the original absorption and A_t is the absorption at time t. Experiments were carried out with some local natural clays of different composition, Table 1. The chemical analysis for some clays was carried out in our laboratory and for others the analysis was made by Saudi Ceramics Company who kindly supplied the clays.

Table 1. Chemical composition of local clay samples

Sample	Color	% Chemical composition										
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O	L.O.I.
C_1	White yellow	7.38	3.68	5.66	23.4	16.63	1.21	1.05	–	–	1.05	39.07
C_3	White	58.49	0.15	0.29	22.57	0.09	0.23	<0.05	<0.05	12.96	1.57	3.36
C_4	Red shale	49.35	25.13	10.17	0.64	1.17	0.44	2.62	1.40	–	–	9.08
C_5	White	58.42	24.43	4.28	0.5	0.18	0.66	0.28	1.69	–	–	9.26
C_6	Variegnated shale	54.07	27.82	10.67	0.65	0.47	0.57	0.55	1.20	–	–	9.00

C_1 : Riyadh area, KSU area.
C_3 : From Triaf area.
C_4 : About 140 Km from Riyadh and 40 Km from Duruma town.
C_5 : Khashm Radi, North of the AlKharj town, about 130 Km from Riyadh.
C_6 : 78 Km on Khurais Road (ruinhill).

Figure 1. shows the absorption spectra of arsenazo and the complex while Fig. 2 shows a linear plot of absorbance against [Th^4] where Lambert-Beer's law is applicable. The extinctoin coefficient was determined and found to be $2.2\times10^4 M^{-1}cm^{-1}$.

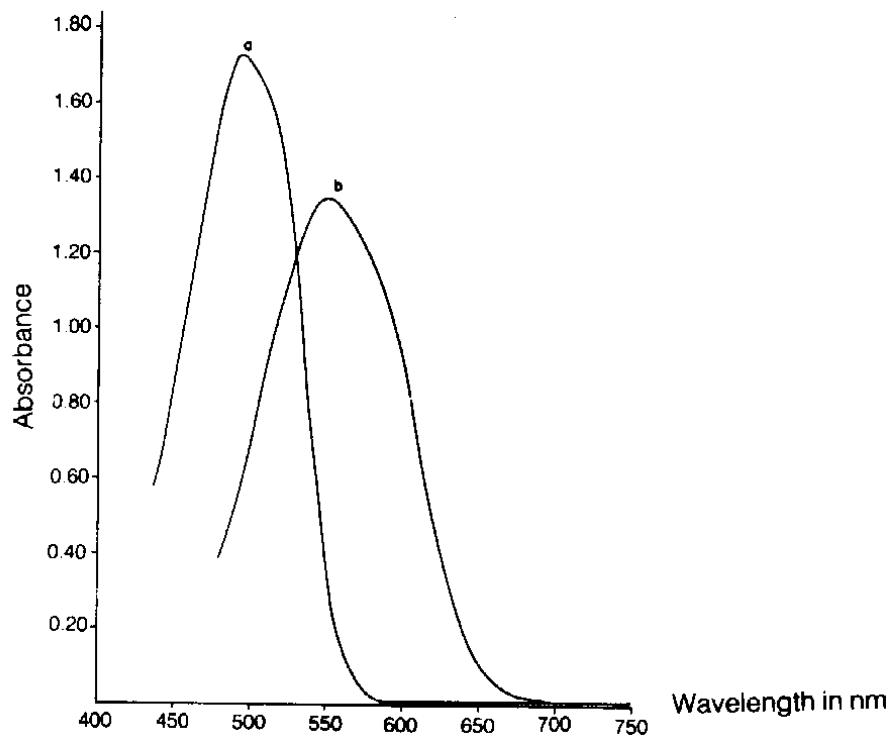

Fig. 1. Absorption spectrum of: (a) 8.0×10^{-5} M Arzenazo at pH 2; (b) 4.0×10^{-5} M Th^4 and 8.0×10^{-5} M Arzenazo at pH 2

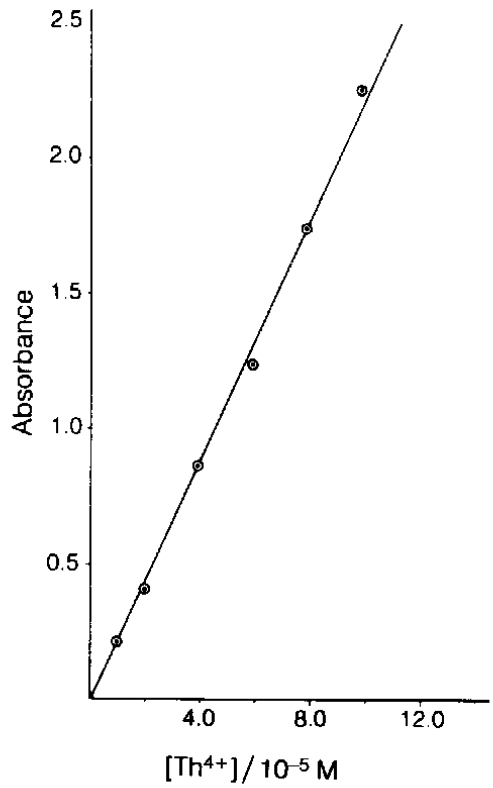

Fig. 2. Plot of absorbance of Th^{4+} complex against $[Th^{4+}]$ at pH 2.

Results and Discussion

Figure 3 shows the variation of % uptake with time for different clays and it is clear that the sorption is very fast process.

At pH > 3.5, thorium is precipitated and separated with clay on centrifugation. Thus the absorbance measurement of thorium in clear solution was found to be zero. At lower pH values, the uptake, at a given pH, was fond to depend on the type of clay. For example at pH $\simeq$ 0.1 the uptakes are 17, 31 and 45% for clays C_4, C_5 and C_6. At pH $\simeq$ 2 the uptakes are 85, 95 and 95% respectively. For these clays (C_4, C_5 and C_6) the pH was nearly constant at the beginning and at the end of reaction. The fact that the uptake is still appreciable even at high hydrogen ion concentration indicates that the highly positive Th^{4+} is competing effectively with H^+. Thus at pH 3 and 10^{-3}M Th^{4+}, the uptake of the latter is almost 100% and the pH was almost constant indicating no appreciable uptake of H^+ by clays. This behavior may be attributed to the high charge density of Th^{4+} in comparison with H^+ and due to the ability of Th^{4+} to intercalated within the layers of the clay than H^+. It might be of interest to mention that the capacity of C_3 towards the sorption of Th^{4+} is the same in the presence of 1 and 3 M HNO_3. The uptake was found to be 100% in both cases. This clay is in fact different from other clays in that it contains ~ 13% phosphate as P_2O_5. Since with

this clay the final pH was much less than ~ 3.5, the possibility of precipitation may be ruled out and the prevailing mechanism is by ionic exchange. There are still, some arguments concerning the mechanism of Th^{4+} uptake by some inorganic exchangers such as Uranyl hydrogen phosphate and Zirconium phosphate [11]. One of these two exchangers was found to remove Th^{4+} by precipitation while the other by ion exchange.

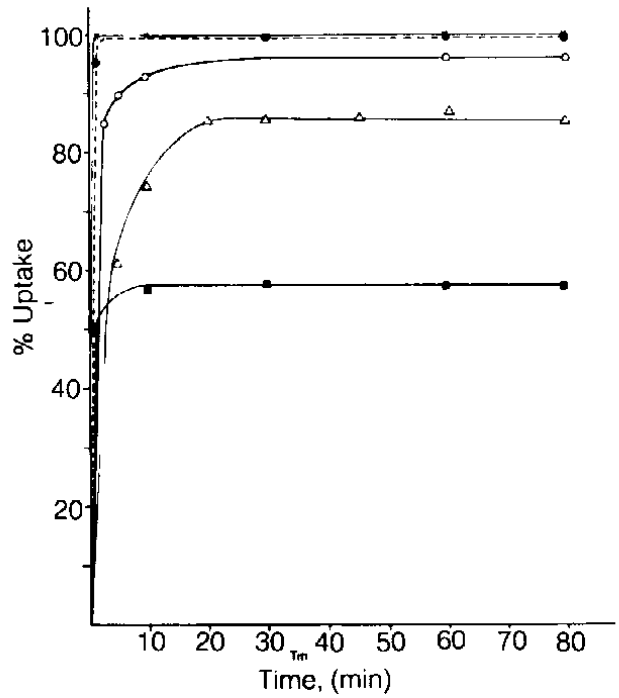

Fig. 3. Effect of time on the uptake of 10^{-3} M Th^{4+} by some natural clays (○) C4, (X) C5 and (●) C6 initial pH = 2.85, (■) C1 and (△) C3 initial pH = 1

Figure 4 shows the variation of equilibrium distribution coefficient,

$$(K_d = (\frac{\%\ \text{uptake}}{100 - \%\ \text{uptake}} \times \frac{V}{m})$$ of 10^{-3}M Th^{4+} at 25°C with pH of some clays. It is clear that K_d increases slowly at low pH values and then it increases rapidly.

Figure 5 shows the variation of the amount of Th^{4+} adsorbed as a function of $[Th^{4+}]$ added both expressed as mg. The amount of clay was 2g and the change in pH was ~ 0.6, for the used clays, but the final pH was always less than the pH value at which precipitation occurs. It is clear from the figure that the equilibrium uptake varies between 7-9 mg Th^{4+}/2g clay. In all cases, these values are reached at ~ 20 mg of added Th^{4+}. It has been reported that the uptake of Th^{4+} by natural clays fits Freundlich adsorption isotherm [19]. The presented data are in agreement with those reported previously. Thus, plotting log $[Th^{4+}]$ versus log $[Th^{4+}]$ added, two straight lines are obtained as can be seen in Fig. 6 indicating the operation of two mechanisms.

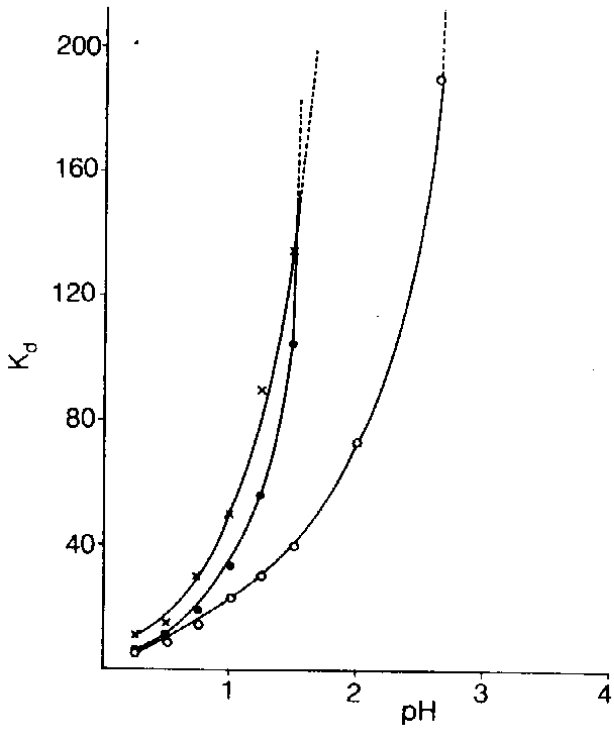

Fig. 4. Variation of K_d of 10^{-3} M Th^{4+} with pH for some clays. ○ C_4, × C_5 and ● C_6. Velocity of shaking = 125 ◯ min^{-1}.

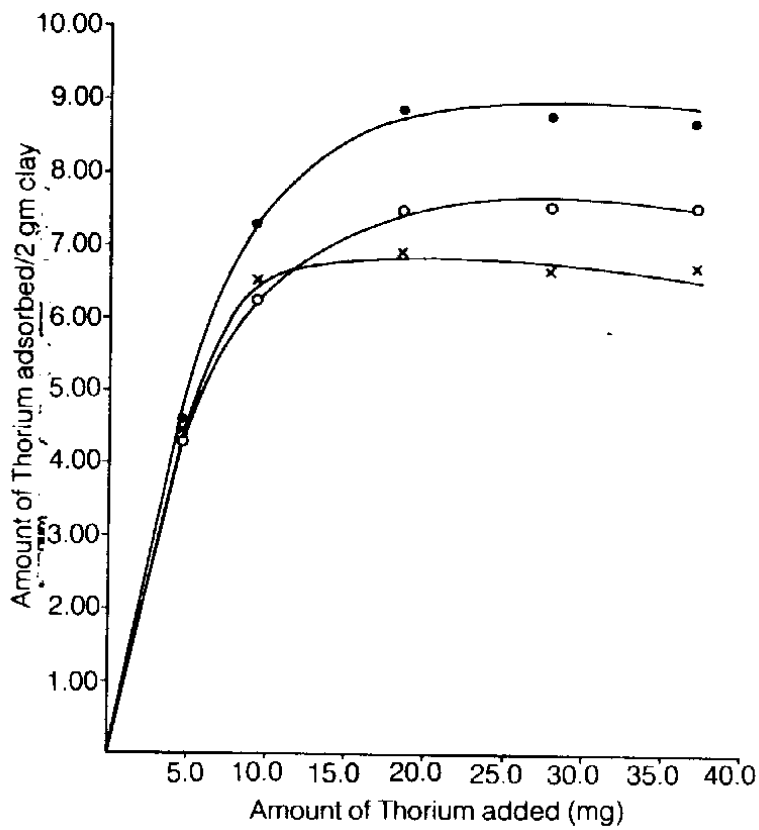

Fig. 5. Variation of Th^{4+} adsorbed by some clays with Th^{4+} added ○ C4, / C5 and ● C6,

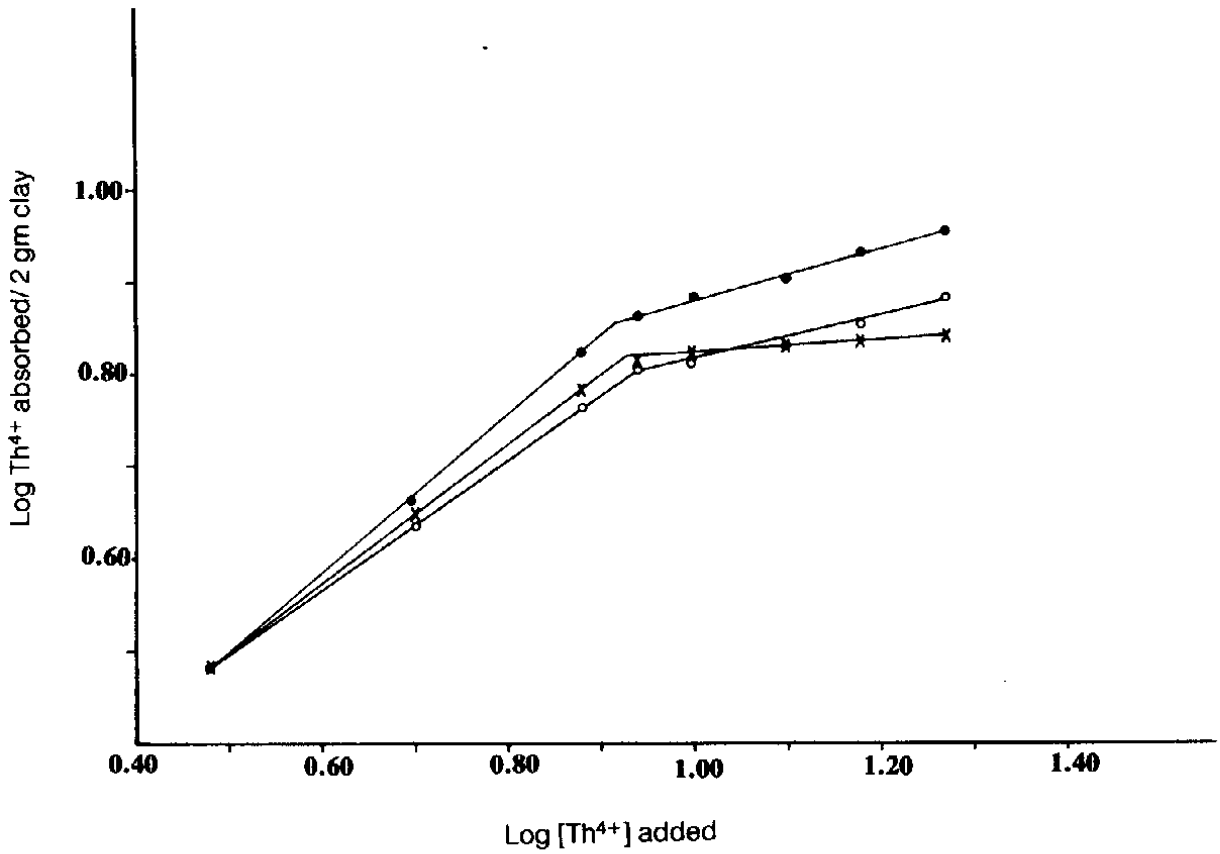

Fig. 6. The Freundlish absorption isotherm of Th^{4+} by some natural clays ○ C4 × C5 and ● C6.

The effect of heating temperature on the uptake of some clays is shown in Fig. 7. The examined clays show some general features, where three of those examined showed that the uptake is constant with increasing temperature of treatment. This constancy is not the same but it is in the range 200-400°C. The uptake then decreases sharply where it drops from ~100% to 20-35%. The behavior of the clay (C_3) which contains phosphate is somewhat different from other clays. Its uptake increases gradually by ~ 15% in going from 100°C to 400°C and then decreases to ~ 10% at 800°C. The factors that govern the uptake of Th^{4+} by preheated clays are expected to be dehydration effects, movements of exchangeable cations inside the clay lattice, ... etc. [20].

When the clays are treated with different acids the pH of their solution was ~ 2. Some of these clays were used to decontaminate Th^{4+} and the results are shown in Table 2. It is clear that the uptake by treated clays is always less than that by untreated clays and the uptake is in the order HC1 > HNO_3 > H_3PO_4. The participa-

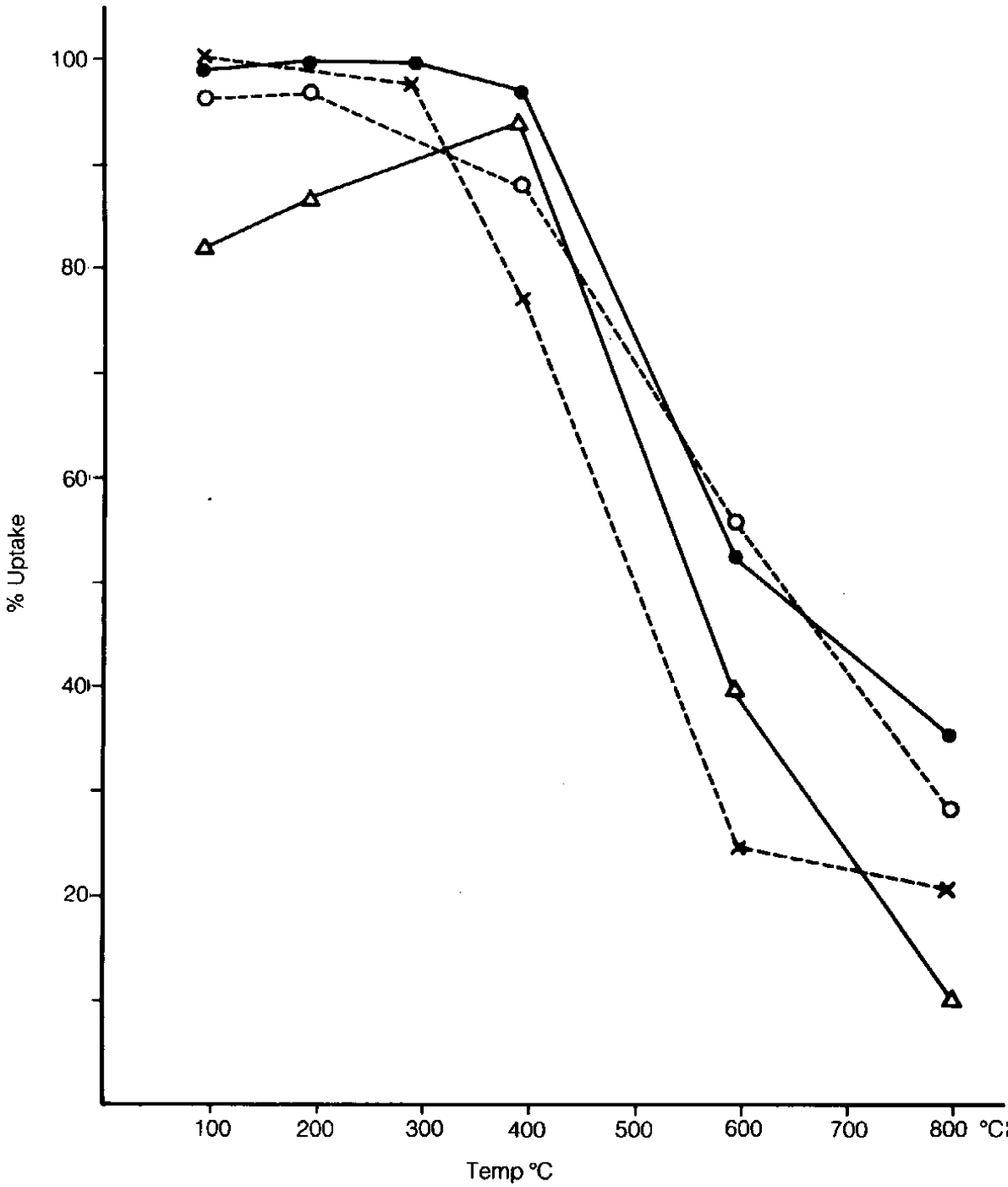

Fig. 7. Variation of % uptake of 10^{-3} M Th^{4+} with some heated clays. △ C3, ○ C4, × C5 and ● C6. Velocity of shaking = 125 ○ min^{-1}.

tion of the anions of the acids used in the treatment in complex formation may be the reason for this diverse behavior. A further work is needed in this field to clarify the effect of these anions.

Table 2. Effect of acid treatment of natural clays on the % uptake of 10^{-3}M Th^{4+} from aqueous solutions at 25°C

Clay	% uptake				
	Natural (3.00)*	HCl (1.98)*	HNO_3 (2.05)*	H_3PO_4 (1.6)*	H_2SO_4 (1.23)*
C_4	97.0	82.0	81.0	44.0	21.0
C_5	100.0	91.0	85.9	51.0	19.3
C_6	99.0	87.4	72.3	52.2	41.8

*The figures refer to the initial pH values.

Different ions were used to compete with Th^{4+} for the sorption on some selected clays. These ions are Li^+, Na^+, Cs^+, Mg^{2+}, Cr^{3+} and Al^{3+}. The concentrations of these ions was in the range $5\times10^{-4} - 10^{-2}$M and the initial pH was ~ 3.2. All stated ions have no or negligible effect except the last two (Cr^{3+} and Al^{3+}). The effect of the last two ions is shown in Table 3. The effect of Al^{3+} and Cr^{3+} is only pronounced at concentrations of these ion $\gtrsim 5 \times 10^{-3}$M, i.e. five folds of that of Th^{4+}. Three factors usually affect the ability of an ion to compete effectively with another. These factors are the charge on the ion, its ionic radius and the hydration energy of the competing ion. For an ion to be effective in competition reactions, its charge and hydration energy must be high and its radius shold be small. The radius of Th^{4+} is 0.9 Å [2] which is less than Cs^+ and Sr^{2+} and is about that of Na^+. The other ions have less radii than Th^{4+}. The hydration energies of these ions are quite low in comparison of say Al^{3+} and Cr^{3+} and the charge on all ions are less than that on Th^{4+}. Therefore it is easy to understand why there is no observed effect of some ions on the sorption of Th^{4+}. For Al^{3+} and Cr^{3+}, their effect is mainly due to their ionic radii (0.51 and 0.63 Å) which is approximately fit with the porse on the clay surface and high hydration energies (4640 and 4381 kJ mol^{-1}). It is also obvious that these two ions need to be at much higher concentration so that they become competitive. From the above discussion, it may be concluded that, the charge on the ion is more important than the radius and hydration energy of the ion in determining the effectiveness of a competition reaction.

Table 4 shows the variation of % uptake of 10^{-3}M Th^{4+} by some synthetic exchangers, and some metal oxides. The initial pH of Th^{4+} solution was 2.82 and the final pH was found to depend on the exchanger, and these pH values are included in the Table. It is obvious that the uptake is very dependent on the type of sorbent. The uptake of Th^{4+} by the sorbent can be classified in the following manner:

Table 3. Effect of competing ions on the sorptin of 10^{-3}M Th^{4+} by natural clays from aqueous solutions at 25°C

Competing ion	[ion]M	% uptake by		
	O	C_4	C_5	C_6
		97.0	**99.0**	**100.0**
Al^{3+}	5×10^{-4}	97.0	100.0	98.0
	1×10^{-3}	97.0	100.0	98.0
	5×10^{-3}	84.0	85.0	88.0
	1×10^{-2}	73.0	86.0	85.0
Cr^{3+}	5×10^{-4}	97.0	100.0	100.0
	1×10^{-3}	89.0	98.0	100.0
	5×10^{-3}	75.0	83.0	80.0
	1×10^{-2}	62.0	67.0	65.0

Table 4. The % uptake of thorium ions by synthetic exchangers used, $[Th^{4+}] = 10^{-3}$ M. Initial pH = 2.82

Exchanger	Final pH	% Uptake
Amberlite IR 120	3.51	100
Molecular sieve 4A	5.05	69
Dowex-50	2.14	100
Amberlite resin	2.72	0
Fe_3O_4 Magnetic	3.15	42
Fe_2O_3	2.69	26
Fe_2O_3 calcined	2.95	57
TiO_2	2.60	100
Alumina (basic)	5.23	40
Alumina (neutral)	5.00	52

1. Those sorbents having a final pH of $\lesssim 3.5$, the uptake varies in the range 0-100%. Only Amberlite resin gave a zero uptake, while Dowex 50 and TiO_2 gave 100% at final pHs of 2.14 and 2.6 respectively. For iron oxides the uptake varies between 26 and 57% and the pHs in the range 2.69–3.15.

2. In this category the pH range is $\sim 4.6 - 6.1$ and the precipitation of Th^{4+} is expected. In case of Amberlite IR 120, the uptake is 100% and the mechanism seems to be mainly as due to ion exchange. For molecular sieve 4A the uptake is 69%

and the precipitation of Th^{4+} is probably dominant due to the high pH value. The most striking behavior was that of the Alumina (basic or neutral) where the pH is ~ 6.1, but the uptake is 39 and 50% respectively. There is no ready explanation for this behavior but it may be due to complex formation.

Three of the above mentioned sorbents were chosen to follow their uptake as a function of $[Th^{4+}]$ and the results are shown in Table 5. It is obvious that their initial and final pHs as well as the uptake are dependent on $[Th^{4+}]$. Thus, the final pHs for Amberlite IR 120 and TiO_2 are close to each other but the uptake is rather different. On the other hand, the final pH for Dowex 50 is less by about 2 pH units at the same concentrations, but the uptake is similar. It is also clear that the Amberilite IR 120 and Dowex-50 have higher capacity than TiO_2 and the natural clays as can be seen in Table 5. It is possible, however, to state that natural clays are very good sorbent for thorium and their capacity is not far from the synthetic exchangers or some metal oxides, and they have the advantage of having low prices.

Table 5. The % uptake of thorium by some synthetic exchangers

Exchanger	Initial concentration		Initial pH	Final pH	Uptake	
	M	mg/20ml			%	mg/2 gm clay
Amberlite IR 120	10^{-3}	4.64	3.05	4.06	100	4.64
	5×10^{-3}	23.2	3.02	3.80	100	23.2
	10^{-2}	46.4	2.90	3.42	98	45.5
	5×10^{-2}	232	2.60	2.90	87	202
	10^{-1}	464	2.30	2.68	39	181
Dowex 50	10^{-3}	4.64	3.05	1.82	100	4.64
	5×10^{-3}	23.2	3.02	1.76	100	23.2
	10^{-2}	46.2	2.90	1.52	99	460
	5×10^{-2}	232	2.60	0.98	87	202
	10^{-1}	464	2.30	0.87	40	186
TiO_2	10^{-3}	4.64	3.05	2.61	100	4.64
	5×10^{-3}	23.2	3.02	2.53	22	5.10
	10^{-2}	46.4	2.90	2.49	13	6.00
	5×10^{-2}	232	2.60	2.41	–	–
	10^{-1}	464	2.30	2.21	–	–

Table 6 shows the uptake of Th^{4+} by some clays using different compositions of water and methanol. The initial and final pH values are also included in the table where the initial pH is always less than the pH of precipitation. The final pH depends on solvent and nature of the clay but it is clear that it is higher in case of 100% water

and becomes less with the increase of methanol contents. For these systems where pH > 4, it will be assumed that the uptake is mainly due to precipitation. In case of systems having a final pH < 4 the main mechanism is ion exchange and C_4, C_5 and C_6 are representative of this category. For these clays, the uptake is quite high (85-100%) as long as water is present even if its content is as low as 25%. In case of pure methanol the uptake values are 35, 48 and 59% for C_4, C_5 and C_6 respectively and the final pH is almost the same (2.3–2.7) for the clays. For the other two clays (C_1 and C_3), the uptake values are 70 and 27% and their final pHs are 3.5 and 2.8 respectively. The differences in uptake values for these clays are reflections of the complexity of the sorbents.

There are many interpretations of the change in sorption behavior of inorganic exchangers upon the addition of an organic solvent. These include changes in the electrostatic interactions of ions in solution and on solids [21], dehydration effects [22], free energies of transfer or activity coefficients [21]. Therefore the interpretatoin of the behavior of Th^{4+} in the presence of methanol is difficult for the above mentioned possible effects. In addition, the complication due to possible anionic behavior of the clays cannot be ignored.

For tributyl phosphate (TBP), the spectrophotmetric determinaiton of thorium was too difficult due to the difficulties associated with the formation of thorium-arsenazo complex.

In previous work [15, 16] it was shown that two mechanisms prevail in the sorption of Th^{4+} by natural clays. These are the fast film diffusion mechanism and the slower particle diffusion mechanism. The first mechanism was the dominant in these systems. This is supported by the fact that this mechanism is affected by stirring velocity as can be seen in Table 7. From this table we notice that the pH change is small which may exclude the competition by H^+ at this pH. It is quite clear that the uptake is changing considerably with shaking velocity. The kinetic behavior of Th^{4+} adsorbed on the natural clays seems to be different from its behavior by some metal oxides, such as hydrous tin oxide [13, 14].

It is also important to point out that, the intercalation of Th between layers of the clay is the main reaction. This can be checked by an X-ray analysis which is hoped to be studied in future. It is, however, possible to say that the intercalation reaction can be deduced from the decrease in % uptake when the clays are preheated to high temperatures which leads to the collapse of the layer sheet of the clay in C dimension to ~ 9 Å.

Table 6. Effect of organic solvent on the % uptake of Th^{4+} by natural clays; $[Th^{4+}]= 10^{-3}$ M, velocity of shaking 125, min^{-1}

Medium	Clays	C_1		C_3		C_4		C_5		C_6	
	Initial pH	% Uptake	Final pH	% Uptake	Final pH	% Uptake	Final pH	% Uptake	Final pH	% Uptake	Final pH
100% H_2O	3.35	ppt	7.6	ppt	7.4	97	3.55	100	3.50	99	3.4
3:1 H_2O:Meth	3.05	ppt	7.6	ppt	7.4	97	3.15	99	3.10	98	3.2
1:1 H_2O:Meth	3.05	ppt	7.4	ppt	7.2	89	3.10	100	3.10	99	3.3
1:3 H_2O:Meth	3.00	ppt	7.1	ppt	6.0	85	3.00	100	3.05	99	3.2
100% Meth	1.2	70	3.5	27	2.8	35	2.3	48	2.6	59	2.7

Table 7. Effect of shaking velocity on the uptake of Th^{4+} by some natural clays

Velocity of shaking min^{-1}	C_4		C_5		C_6	
	% Uptake	Final pH	% Uptake	Final pH	% Uptake	Final
0	14.5	2.85	31.5		11.0	
50	29.5	2.95	43.2	3.10	27.5	3.00
75	66.5	3.05	68.5	3.10	44.6	3.05
100	100	3.10	98.0	3.20	92.0	3.05
125	100	3.25	100	3.20	98.0	3.05
≃ 140	100	3.20	100	3.20	98.0	3.05

$[Th^{4+}] = 10^{-3}$ M initial pH = 2.80 Time of shaking = 50 min.

Acknowledgement. The author wishes to thank King Abdulaziz City for Science and Technology (KACST) for supporting this work under Project No. RT-7-32. The author also acknowledges the technical assistance of A. El-Sakik, A.M. Al-Ariefy and M.W.A. Kadi.

References

[1] Seaborg, G.T. and Katz, J.J. *The Actinide Elements.* New York: McGraw Hill Book Co. Inc., 1954.
[2] Cotton, F.A. and Wilkinson, G. *Advanced Inorganic Chemistry.* 3rd edition. New York: Interscience Publishers, 1972.
[3] Hietanen, S. "The Mechanism of Thorium (IV) and Uranium (IV) Hydrolysis." *Rec. Tran. Chim.*, 75 (1956), 711-715.
[4] Day, Jr., R.A. and Stoughton, R.W. "Chemistry of Thorium in Aqueous Solutions." *J. Am. Chem. Soc.*, 72 (1950), 5662-5666.
[5] Fomin, V.V. and Maslova, R.N. "Valence Condition of Phosphorous 32 Formed by Reaction S(n,p) P." *Zhur, Neorg Khim.*, 1 (1956), 337-341.
[6] Britton, H.T.S. *Hydrogen Ions.* Vol. II. London: Chapman and Hall, 1942.
[7] Milkey, R.G. "Stability of Dilute Solutions of Uranium Lead and Thorium Ions." *Anal. Chem.*, 26 (1954), 1800-1803.
[8] Beran, M. "Monovdear Hydrolysis Complexes of Thorium." *Collect. Czech. Chem. Commun.*, 32 (1967), 1368-1373.
[9] Zhukov, A.I.; Kazant Serv, EI. and Unosov, N.N. "Sorption of Thorium by Cation-Exchange Resins." *Zh. Neorg. Khim.*, 7 (1962), 915-920.
[10] Pekarek, V. and Vesely, V. "Study on Uranyl Phosphates II. Sorption Properties of Some 1 to 4 Valent Cations on Uranyl Hydrogen Phosphate Heated to Various Temperature." *J. Inorg. Nucl. Chem.*, 27 (1966), 1151-1158.
[11] Versely, V. and Pekarek, V. "Sorption on Zirconyl Phosphate and Changes of Its Properties at Higher Temperatures." *J. Inorg. Nucl. Chem.*, 25 (1963), 697-709.
[12] Amphlett, C.B. *Inorganic Ion Exchangers.* Amsterdam: Elsevier Co., 1964.
[13] Misak, N.Z.; H.N. and El-Naggar, I.M., "Sorption Behavior of Uranium and Thorium on Hydrous Tin Oxide from Aqueous and Mixed-solvent HNO_3 Media." *Chem. Scr.*, 22(2), 74-81.

[14] Misak, N.Z.; Salama, H.N. and El-Naggar, I.M. "Sorption Behavior of Uranium and Throium on Hydrus Tin Oxide from Aqueous and Mixed Solvent Sulphuric Acid. *Chem. Scr.*, 23(1), 34-40.

[15] Al-Suhybani, A.A.; Al-Khowaiter, S.; Abou El-Nour, F. and Hallaba, E. "Decontamination Studies of Radioactive Uranium and Thorium Wastes by Natural Clays." *Isotopenpraxis*, 19 (1982), 72-76.

[16] Al-Suhybani, A.A.; Al-Khowaiter, S.; Abou El-Nour, F. and Hallaba, E. "Decontamination Studies of Radioactive Uranium and Thorium Wastes by Natural Clays." *Isotopenpraxis*, 19 (1982), 72-76.

[17] Hallaba, E.; Al-Suyhybani, A.; Al-Khowaiter, S. and Sadik, A. "Improving the Uptake Capacity of Natural Clays by Phosphate and Heat Treatment." *J. Radio and Chem.*, 79 (1983), 51-56.

[18] Snell, F.D. *Photometric and Fluoremetric Methods of Analysis.* Part Two. New York: John-Wiley and Sons, 1978.

[19] Al-Suhybani, A.A. "Use of Local Natural Clays for Radioactive Waste Treatment." Project No. AT-7-32, Second and Third Progress Reports (1988).

[20] Grim, R.C. "Dehydration and the Changes Taking Place on Heating" (1968), New York: *Clay Mineralogy*. New York: McGraw-Hill Book Co. Inc. 2nd edition, 1968.

[21] Marcu, Y. *Ion Exchange and Solvent Extraction.* New York: Marcel Dekker, 1963.

[22] Sakaki, T. "The Harkins-Juraadsorption Isotherm and Its Constants." *Bull. Chem. Soc. Japan*, 26 (1953), 213-218.

[23] Fessler, R.G. and Strobel, H.A. "Nonaqueous Ion Exchange II Univalent Cation Exchange in Alcohols and Methanol methanol Water, and Methanol-ethanol Mixtures." *J. Phys. Chem.* 67 (1963), 2562-2568.

امتزاز الثوريوم بوساطة بعض الأطيان الطبيعية والمبادلات المُصَنّعة وأكاسيد المعادن

عبدالعزيز بن عبدالله السحيباني

قسم الكيمياء، كلية العلوم، جامعة الملك سعود، ص. ب ٢٤٥٥، الرياض ١١٤٥١، المملكة العربية السعودية

(سُلِّمَ في ١٧ ذو القعدة ١٤١٣هـ؛ وقُبل للنشر في ١٠ ربيع الآخر ١٤١٤هـ)

ملخص البحث. إن دراسة امتزاز الثوريوم بوساطة الأطيان الطبيعية المحلية من المحاليل المائية دلت على أن الامتزاز سريع جدًّا ويتبع غالبًا ميكانيكية انتشار الغشاء. ويتم الوصول إلى التوازن خلال ٢٠ دقيقة ويعتمد أساسًا على نوع الطين وقيمة الأس الهيدروجيني للمحلول. وينتج عن المعالجة الحرارية والمعالجة بالحموض نقص في نسبة الامتزاز. ولغرض المقارنة فقد تم استعمال بعض المبادلات المُصَنّعة وأكاسيد المعادن لامتزاز أيون الثوريوم.