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Potentiality of uranium adsorption from crude phosphoric acid using trioctylamine impregnated polyurethane foam

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ABSTRACT

The present work deals with uranium adsorption from crude phosphoric acid using the extraction chromatography technique (solvent impregnated material), *i.e.* tri-*n*-octylamine (TOA) was impregnated onto polyurethane foam. The calculated theoretical capacity of the prepared adsorbent (polyurethane foam) was 1.7 g U/g foam. The attained uranium adsorption efficiency (using ion-exchange columnar technique) was about 22% of its theoretical capacity. Using 1M NaCl-0.1 M H₂SO₄ as eluent solution for uranium from the loaded solvent impregnated foam gave about 96% elution efficiency. © 2011 Trade Science Inc. - INDIA

INTRODUCTION

Phosphoric acid is generally produced in Egypt by attacking phosphate rocks (apatite) by sulfuric acid (wet process method). The produced phosphoric acid contains a number of organic and inorganic impurities. These impurities can affect its grade. The inorganic impurities are represented by heavy metal ions such as copper, cadmium, zinc, lead, uranium, etc. These impurities are considered as hazardous substances. Uranium is the most dangerous heavy metal ion present in phosphoric acid because of its chemical toxicity and radioactivity.

Various processes have been proposed for uranium recovery or removal from phosphoric acid. Chemical precipitation, membrane processes, ion exchange, solvent extraction^[1,2] and adsorption are the most commonly used methods.

The present work deals with recovery of uranium from phosphoric acid by applying the extraction chromatography technique (EXC). This technique combines the advantages of both liquid-liquid extraction and solid-

liquid techniques. Extraction chromatography (solvent impregnated material) characterized by its high binding capacity, selectivity and enhanced mobility of the extractant on the solid surface.

Numerous extractants^[3-7] were used in this technique such as organo-phosphorus extractants like di(2-ethyl hexyl phosphoric acid (DEHPA), CYANEX-272, PC-88A; neutral extractants like tri-*n*-butyl phosphate (TBP) and also basic extractants like tri-*n*-butylamine (TBA). These extractants were impregnated onto different supports like XAD series Amberlite resins, silica gel and activated carbons.

The polyurethane foam have been used as a solid support for specific reagents^[8-10]. The latter belongs to EXC, a process characterized by high selectivity and analytical throughput^[11]. A lot of papers have focused the characterization of the adsorption process by studying the kinetic and thermodynamic aspects related to the extraction process^[12-21].

This study, deals with uranium recovery from phosphoric acid by applying the EXC technique by im-

pregnating tertiary amine (tri-n-octylamine) onto the polyurethane foam.

We have been thoroughly studied the relevant factors affecting solvent impregnation onto foam which included solvent concentration, temperature, impregnation time, mass/volume ratio and diluents type. Also, the studied relevant factors affecting uranium adsorption onto the solvent impregnated foam involved initial uranium concentration, contact time, pH and temperature.

EXPERIMENTAL

Materials and analytical procedure

The working phosphoric acid sample used in this study (42% P₂O₅) was provided by the *Abu-Zaabal Co., Egypt*. Its average chemical composition is shown in TABLE 1:

A uranium stock standard solution assaying 20000 mg/L was prepared by dissolving 3.564 g of uranyl acetate [UO₂(CH₃COO)₂·2H₂O] in 100 ml distilled water of *BDH Chemicals Ltd. Poole, England* in a synthetic phosphoric acid solution.

Different concentrations of tri-n-octylamine (C₂₄H₅₁N) Mol. Wt 353.67, boiling point 365-367 °C, Density 0.809 g/mL of *Riedel-deHaen* (assaying 95%) were used.

Uranium was analyzed in the different working aqueous phases using the ArsenazoIII method^[22]. Absorbance of the formed uranium ArsenazoIII complex was measured at 650 nm against proper standard solutions using a Lambda3 UV/VIS spectrophotometer (*Perkin-Elmer, USA*).

TABLE 1 : Chemical composition of the working phosphoric acid sample

Constituent	%	Constituent	mg/L
P ₂ O ₅	42.00	Mn	673.3
SO ₄ ²⁻	6.10	Zn	358.9
Fe	2.50	U	60.0
Ca	0.26	Pb	53.9
Mg	0.17	Ni	7.8
		Co	7.7

The working polyurethane foam sample was obtained from *Foam Industries Co. Cairo, Egypt* where foam plugs of 4.5 cm in diameter and 2.2 cm long (average weight = 0.500 ± 0.002 g), were cut from a foams

sheet. Each foam plug was squeezed in 2 M HCl for 1 hr, washed with distilled water until free from HCl, squeezed again, and air-dried overnight before being ready for use.

Preparation of the impregnated foam

In order to study the factors affecting the impregnation process, several series of impregnation experiments have been performed by shaking 0.05g of dry clean foam samples with the properly prepared impregnation solutions by magnetic stirrers. The amount of solvent impregnated on the foam samples were calculated by the difference between the foam weight before and after the impregnation process. The studied factors involved solvent concentration, impregnation temperature, impregnation time, mass/volume ratio and diluents type.

After the end of the impregnation experiments, the foam was dried in the drying oven for one hr (at 60 °C) to evaporate the diluent and leaving the diffused solvent into the foam pores.

Equilibrium studies

For studying the relevant adsorption factors, several series of experiments have been performed using the uranium synthetic phosphoric acid solution. These factors involved contact time, initial uranium concentration, pH and the adsorption temperature. From the obtained results, Langmuir isotherm were resolved. These batch adsorption experiments were performed by shaking 0.05 g of the impregnated foam sample with 20 ml of the uranium synthetic phosphoric acid solution (200 ppm) using a magnetic stirrer. The adsorbed amounts of uranium were calculated by the difference between its equilibrium and initial concentrations.

Columnar procedure

The uranium adsorption and elution studies have been performed in a glass column of 1 cm diameter packed with 1 g of the previously impregnated foam. Glass wool plugs were inserted at the bottom and top of the foam bed.

The foam bed was then loaded with uranium by passing the crude phosphoric acid through the prepared column at an initial flow rate of 2 ml/min. Periodical samples were taken each 20 ml throughput volume for uranium analysis until saturation of the foam bed was reached.

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For eluting the loaded uranium from the foam beds, the latter was firstly washed with a phosphoric acid solution having the same molarity of the working liquor. This was then followed by studying the proper eluent solutions, namely 1 M NaCl acidified with 0.1 M H_2SO_4 or 0.5 M HCl, a 0.5 M Na_2CO_3 /1.5 M CaSO_4 mixed solution and a 0.5 M citric acid solution. The applied flow rate was fixed at 1 ml/min. Periodical samples were collected in each elution experiment every 10 ml throughput volume fraction for uranium analysis.

RESULTS AND DISCUSSION

Results of relevant factors of foam impregnation

(A) Effect of solvent concentration

In order to study the effect of solvent (TOA) concentration upon its impregnated amounts on the working foam sample, a series of impregnation experiments were performed under the following fixed conditions, namely, impregnation temperature of about 25 °C for 1 h using volume/mass ratio of 60/1 and using benzene as a diluent. The studied solvent concentrations range was from 0.025 up to 1 M. The obtained results are plotted in Figure 1, from which it is clearly obvious that the amount of solvent loaded onto the foam increased with increasing the solvent concentration from 0.025 to 0.5 M. This may be due to the increase of the amine amount available in the impregnation solution. After the 5th experiment, no significant increase of the amount of the loaded solvent could be observed. This could be explained as due to filling all the foam surface areas by the solvent.

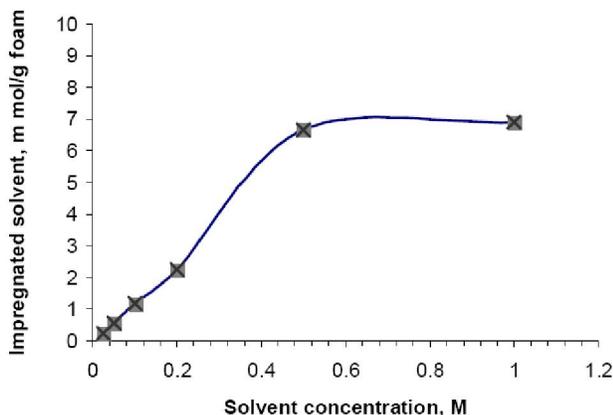


Figure 1 : Effect of solvent TOA concentration upon the loaded amount onto polyurethane foam.

(B) Effect of impregnation time

In order to study the effect of impregnation time (shaking) time upon the amount of TOA impregnated on the working foam sample, a series of impregnation experiments were performed under fixed conditions of 25 °C as impregnation temperature, 0.5 M amine concentration and 60/1 volume/mass ratio and using benzene as a diluent. The studied impregnation time ranged from 1 up to 20 hr. The obtained data were plotted in Figure 2. From the latter, it is clearly obvious that the amounts of TOA loaded onto the foam increased with increasing the impregnation time from 1 up to 5hr. Beyond the 5 hrs impregnation time there is no significant increase in the amount of the loaded solvent. Accordingly the 5hrs time could be recommended as the best impregnation time.

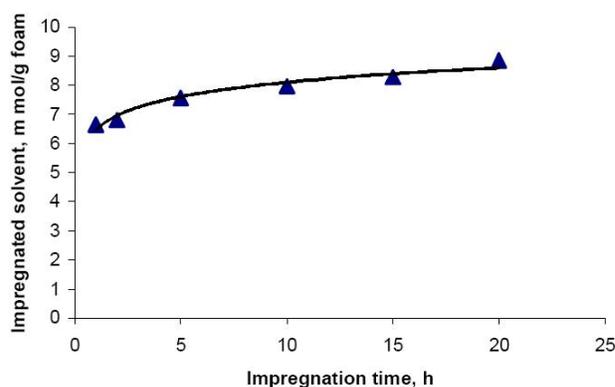


Figure 2 : Effect of impregnation time upon the loaded amount of TOA onto polyurethane foam.

(C) Effect of volume/mass ratio

For studying the effect of volume / mass ratio upon the amount of TOA impregnated on the working foam sample, a series of impregnation experiments were performed under fixed conditions of 25°C as impregnation temperature, 5 hrs using affixed amine concentration of 0.5 M and using benzene as a diluent. The studied impregnation solution volume / foam mass ratios ranged from 20/1 up to 90/1. The obtained results were plotted in Figure 3. From the latter, it is clearly obvious that the amounts of the loaded solvent onto the foam increased with increasing the impregnation solution volume (owing to the increase of the amine amounts in the solution). Beyond the 60/1 volume / mass ratio, there is no significant increase in the amount of the loaded solvent. Accordingly, 60/1 volume / mass ratio could be recommended as the optimum ratio, at least instead of the handling large volumes of impregnation solutions.

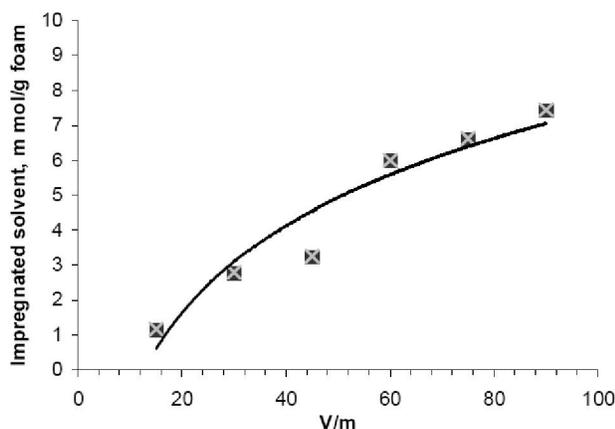


Figure 3 : Effect of impregnation solution volume / foam mass ratio upon the loaded amount of TOA onto polyurethane foam.

(D) Effect of impregnation temperature

In order to study the effect of impregnation temperature upon the amount of TOA impregnated on the working foam sample, a series of impregnation experiments were performed under fixed conditions of, using impregnation solution (TOA) concentration of 0.5M for 5 hrs using a volume /mass ratio of 60/1 and using benzene as a diluent. The studied impregnation temperature range was from 25 up to 70 °C. It is important to mention herein that the impregnation experiments were performed under condenser. From the obtained are plotted in Figure 4. From this figure, one could observe that the amounts of the loaded solvent increases with increasing the impregnation temperature form 25 till 40°C. Raising the temperature above 40 °C, led to a pronounced decrease in the surface properties. This behavior may be due to a probable change in foam surface properties (i.e. become more flexible and began to shrank). Accordingly, it could be recommended that the temperature of 40 °C is a optimum impregnation temperature.

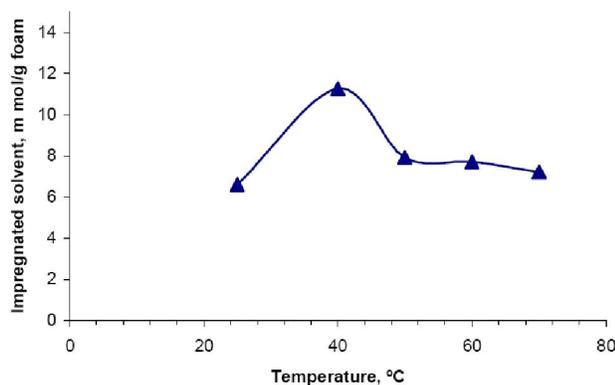


Figure 4 : Effect of impregnation temperature upon the loaded amount of TOA onto polyurethane foam.

(E) Effect of diluent type

In fact, the impregnation solvent solution needs the use of a diluent in order to reduce its viscosity for the increase of its extension on the surface of the dry foam as well as improving its ability to reach the interior foam pores. However, in order to determine the effect of diluent type upon the impregnation process, several impregnation experiments were carried out using different types of diluents the TOA solvent, namely, benzene, toluene, acetone, methanol, and cyclo-hexane. These impregnation experiments were performed under fixed conditions of using impregnation solution (TOA) concentration of 0.5M, 5 hrs for and using volume /mass ratio of 60/1 at 40 °C. The obtained results were summarized in TABLE 2. From the latter, it is clearly obvious that benzene could be considered as the diluted for the studied solvent (TOA).

TABLE 2 : Effect of diluent type upon the loaded TOA amounts onto the dry foam.

Diluent type	Loaded TOA, m mol/g foam
Benzene	6.3584
Toluene	4.5160
Acetone	5.3528
Methanol	3.7584
Cyclo-hexane	4.5984

(F) Choice of the optimum conditions

From the previously mentioned results of the study of the relevant factors affecting the foam impregnation we could recommend the choice of the following optimum conditions (keeping in mind the economic considerations): using 0.5M as the solvent (TOA) concentration, 5hrs as the impregnation time, volume /mass ratio of 60/1, 40 °C as the impregnation temperature and benzene as a diluent.

(G) Infrared spectroscopy

The impregnation process of the TOA on polyurethane foam is mainly due to two phenomena, i.e. pore filling Figure 5 and surface adsorption. This suggestion of filling the TOA solvent of foam pores is confirmed by a detailed investigation of qualitative IR spectroscopic characterization of the polyurethane foam before and after the impregnation step. The spectrum of untreated polyurethane foam is shown in Figure 6a, and that after loading with TOA is shown in

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Figure 6b. Figure 6a (before loading the TOA) shows the characteristic conjugated amides compounds band at 3413 cm^{-1} , the CH aliphatic band at 2927.4 cm^{-1} , the CN bands at 2358 and 2225.4 cm^{-1} , C=O bands at 1727.9 , 1614.1 and 1549.5 . Bands in the range of $1450.2 - 455.1\text{ cm}^{-1}$ arising from out of C-C, C-N, C-O and C-X (X= halogen) compounds. Figure 6b (after loading The TOA) shows a new CN stretching band at 2354.66 cm^{-1} (characteristic band for the TOA foam). Also The stretching band of benzene cycle CH is clearly shown at 3764 cm^{-1} .

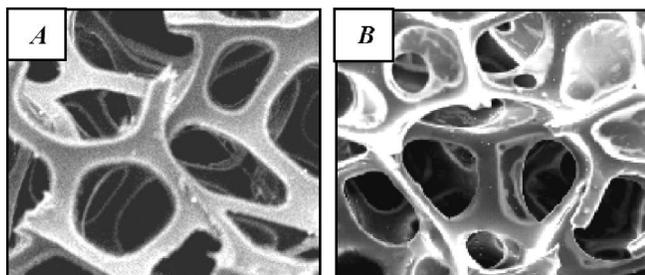


Figure 5 : (A) and (B) SEM photographs of the polyurethane foam surface before and after impregnation with TOA.



Figure 6 : (a) IR Spectra of polyurethane foam, (b) IR spectra polyurethane foam impregnated with TOA.

Results of equilibrium studies

In order to study the relevant factors affecting uranium adsorption onto the prepared solvent impregnated polyurethane foam, suitable amount (2g) of the foam was treated by the make use of the choiced optimum impregnation conditions. The prepared impregnated foam amount was then divided into suitable portions for performing the equilibrium studies. The latter involved effect of contact time, effect of initial uranium concentration, effect of pH and effect of the adsorption temperature.

(A) Effect of contact time

In order to study the effect of contact time upon uranium adsorption on the prepared TOA impregnated foam, a series of adsorption experiments was performed by contacting a fixed weight (0.05 g) with a uranium solution having a concentration of 200 mg/L

at room temperature ($\sim 25\text{ }^{\circ}\text{C}$) and pH 0.1. The studied time intervals ranged from 0.5 up to 5 hours. The obtained results were plotted in Figure 7. From this figure, the uranium adsorption efficiency attained about 93% after the first experiment (of 0.5hr). By increasing the shaking time behind 0.5 hr, slight uranium adsorption efficiencies gained slight increase (95% at the experiment of 1 hr shaking time). After the experiment of 1 hr shaking time, the figure show a clear plateau. Therefore, the 1 hr shaking time could be choiced as the appropriate time.

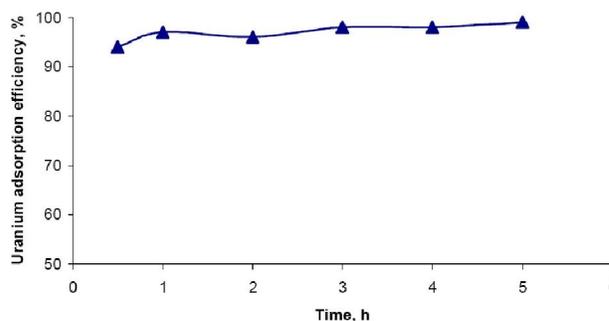


Figure 7 : Effect of contact time upon uranium adsorption efficiency onto impregnated foam with TOA.

(B) Effect of initial uranium concentration

For studying the effect initial uranium concentration upon the adsorption efficiency onto the prepared impregnated foam, a series of experiments was performed by contacting a fixed weight (0.05 g) for 1 hr at room temperature ($\approx 25\text{ }^{\circ}\text{C}$) and pH 0.1. The studied initial uranium concentrations ranged from 200 up to 20000 mg/L. TABLE 3 summarizes the obtained results and Figure 8 shows its plotting. From the obtained data, it is clearly obvious that uranium adsorp-

TABLE 3 : Results of uranium uptake by the prepared impregnated foam.

Initial Concentration, mg/l	Final Concentration, mg/l	Uptake, g/g	Uranium Adsorption, %
20000	15700	1.72	21.50
10000	4292	2.28	57.08
5000	2170	1.13	56.60
3000	1150	0.74	61.66
1000	24	0.39	97.60
800	14	0.31	98.25
600	8	0.23	98.66
400	6	0.15	98.50
200	2	0.06	82.00

tion efficiency decreases with increasing its initial concentration. The (theoretical) uranium adsorption capacity of the impregnated foam was determined (from Figure 8) to be about 1.7 g U/g foam.

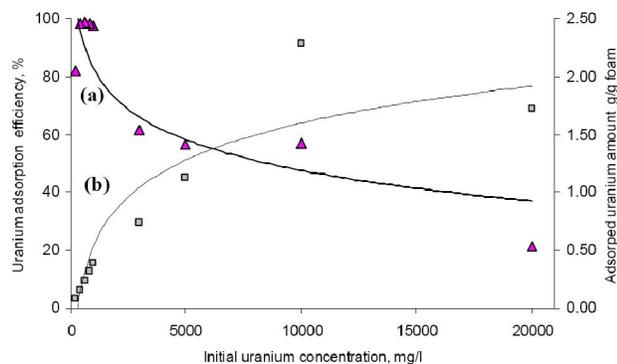


Figure 8 : Effect of uranium concentrations on adsorption onto the prepared foam (a, % and b, g/g foam).

(a) Adsorption isotherms

Several common adsorption isotherm models were considered to fit the obtained isotherm data under the equilibrium adsorption of the TOA impregnated foam (sorbent). Examples of the latter models are Langmuir and Freundlich isotherms.

(I) Langmuir isotherm

According to the Langmuir model, adsorption occurs uniformly on the active sites of the sorbent, and once a sorbate occupies a site, no further sorption can take place at this site. Thus, the Langmuir model is given by the following equation^[23,24].

$$C_e/q_e = 1/bQ_0 + C_e/Q_0 \quad (1)$$

where Q_0 and b , the Langmuir constants, are the saturated monolayer sorption capacity and the sorption equilibrium constant, respectively. A plot of C_e/q_e versus C_e would result in a straight line with a slope of $(1/bQ_0)$ and intercept of $1/Q_0$ as seen in Figure 9. The Langmuir parameters given in TABLE 4 can be used to predict the affinity between the sorbate and sorbent using the dimensionless separation factor R_L ^[25,26],

$$R_L = 1/(1 + bC_0) \quad (2)$$

R_L value indicate the type of isotherm to be irreversible ($RL = 0$), favourable ($0 < RL < 1$), linear ($RL = 1$) and unfavourable ($RL > 1$)^[27,28]. The values of R_L for adsorption of uranium(VI) onto TOA impregnated foam are shown in TABLE 5, which indicate that adsorption of uranium(VI) is more favorable at higher initial uranium(VI) concentrations than at lower concentrations.

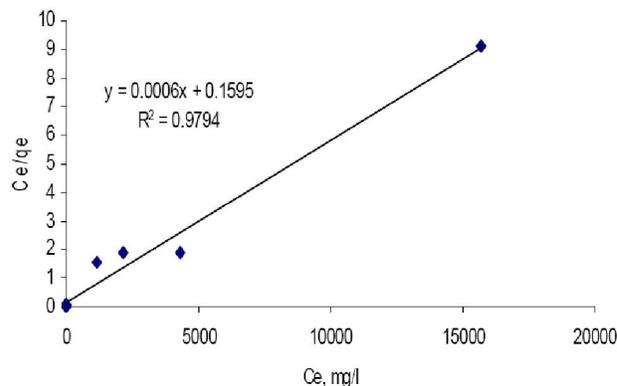


Figure 9 : Langmuir isotherm plots for adsorption of uranium onto TOA impregnated foam.

TABLE 4 : Langmuir and Freundlich parameters for uranium adsorption onto TOA impregnated foam.

Metal	Adsorbent	Langmuir model parameters			Freundlich model parameters		
		Q_0 (mg/g)	b (L/mg)	R^2	$1/n$	K_f (mg/g)	R^2
Uranium	TOA impregnated foam	1700	265.8	0.979	2.95	90.0	0.9044

TABLE 5 : Separation factor R_L of uranium(VI) adsorbed onto TOA impregnated foam

C_0 , mg/L	R_L , (10^{-7})
200	188.107
400	94.054
600	62.703
800	47.027
1000	37.622
3000	12.540
5000	7.524
10000	3.762
20000	1.881

(II) Freundlich isotherm

The Freundlich model stipulate that the ratio of solute adsorbed to the solute concentration is a function of the solution. The empirical model was shown to be consistent with exponential distribution of active centers, characteristic of heterogeneous surfaces. The amount of solute adsorbed at equilibrium, q_e , is related to the concentration of solute in the solution, C_e , following^[23,24]:

$$q_e = K_F C_e^{1/n} \quad (3)$$

This expression can be linearized to give

$$\log q_e = \log K_F + 1/n \log C_e \quad (4)$$

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where K_F and n are the Freundlich constants, which represent sorption capacity and sorption intensity, respectively. A plot of $\log q_e$ versus $\log C_e$ would result in a straight line with a slope of $(1/n)$ and intercept of $\log K_F$ as seen in Figure 10. Freundlich constants are given in TABLE 4.

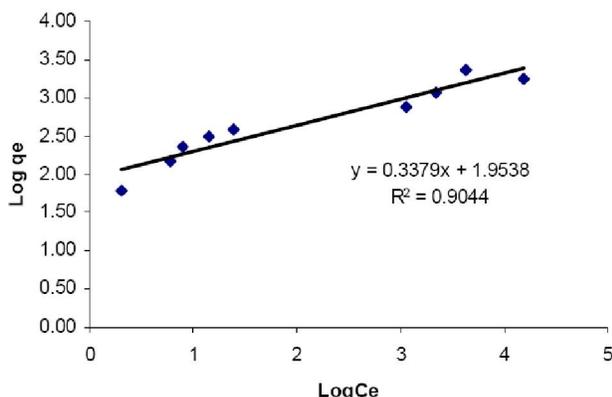


Figure 10 : Freundlich isotherm plots for adsorption of uranium into TOA impregnated foam.

The experimental data shows that the adsorption of uranium onto TOA impregnated foam fitted well with Langmuir than Freundlich isotherm.

(C) Effect of pH

In order to study the effect of pH value of the working solution upon uranium adsorption onto the prepared impregnated foam, a series of experiments was performed using different pH values ranged from 0.1 up to 8.2. The experiments were performed under constant initial uranium concentration of 200 mg/L at room temperature ($\sim 25^\circ\text{C}$) for 1 hr shaking time. For this purpose, different aliquots of the uranium synthetic solution (200 ppm) treated with H_2SO_4 or NaOH solution to reach the required pH values. The obtained results are plotted in Figure 11. From this figure, one could observe that no significant change (in uranium adsorption efficiency) between pH 0.1–3. Further increase of the pH value behind pH 3 results in a significant decrease in uranium adsorption efficiency. The decrease of uranium adsorption efficiency by increasing the pH values refers to hydrolyzation of uranyl ions (at pH = 4) which led to the turbidity and even precipitation. In addition as cited in literature^[29], amines can convert to free salts up to pH4. Accordingly, it can thus be concluded that the pH value of 1 ± 0.2 could be considered as the optimum acidity of the working solution.

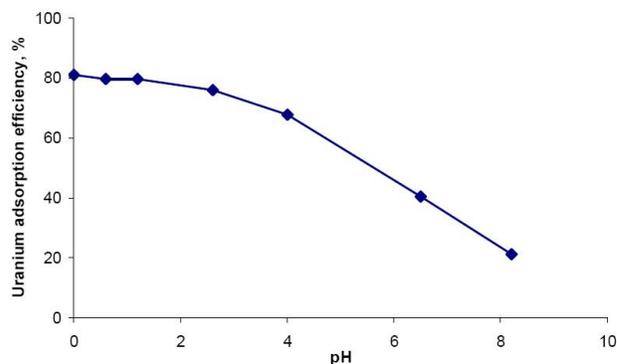


Figure 11 : Effect of solution pH upon uranium adsorption efficiency onto TOA impregnated foam.

(D) Effect of adsorption temperature

To study the effect of temperature upon the uranium adsorption onto the prepared foam sample, a series of adsorption experiments was performed using different temperatures ranging from 25 up to 60°C . In these experiments the other parameters were kept constant, i.e. initial uranium concentration of 200 mg/L, pH value 1 and 1 hr as a contact time. The obtained results were plotted in Figure 12. It is clearly obvious (from this figure) that uranium adsorption efficiency decreased with increasing the temperature. This may be due to foam surface change (became more flexible) which led to decreasing in the foam volume. Therefore, we can conclude that the room temperature ($\sim 25^\circ\text{C}$) is the most suitable temperature in the experimental uranium adsorption (onto the impregnated foam) study.

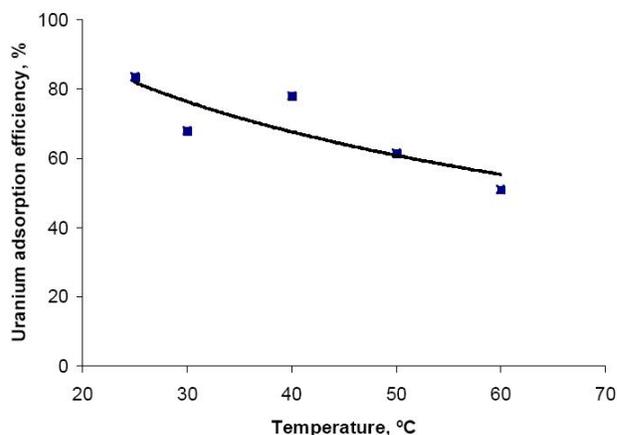


Figure 12 : Effect of temperature upon uranium adsorption efficiency onto TOA impregnated foam.

Results of columnar application

(A) Uranium recovery

As previously mentioned, impregnated foam has a very satisfactory uranium adsorption capacity (about

1.7 g U/g foam). In the present work, the study of uranium recovery from crude phosphoric acid was carried out using a glass column packed with 1 g of the prepared foam.

(a) Uranium adsorption

Adsorption operation (loading) of uranium is the first step in the ion-exchange process. The obtained data of uranium adsorption efficiencies was plotted in Figure 13. This figure is a plot of the collected effluent samples vs. throughput volumes (adsorption or loading curve). Actual uranium breakthrough has been observed at the 25th sample fraction (throughput volume of 5 L) where uranium concentration in the effluent attains 2 mg/L (about 3 % of that in the feed). On the other hand, an almost adsorbent saturation at the 30th sample fraction (throughput volume 10.0 L). Systematic calculation of the loaded uranium content from its analysis in the effluent samples revealed that only 0.381 g of uranium have been adsorbed. Comparing this loading capacity with the theoretical capacity of the prepared foam (about 1.7 g U/g of the working adsorbent), indicates that under the working conditions about 27.3% of the theoretical capacity was realized. The decrease in TOA impregnated foam capacity after contacting with the working sample may be due to the competition between uranium and different ions in crude phosphoric acid (as iron).

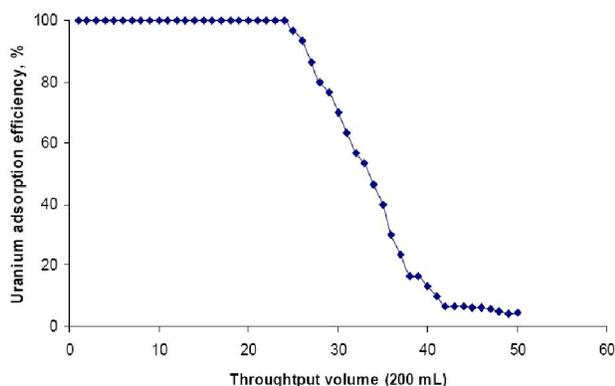


Figure 13 : Uranium adsorption curve from phosphoric acid by TOA impregnated polyurethane foam.

(b) Uranium elution

The following solutions $\text{NaCl-H}_2\text{SO}_4$, NaCl-HCl , $\text{Na}_2\text{CO}_3\text{-CaSO}_4$ and citric ($\text{C}_6\text{H}_8\text{O}_6$) acid were tested for uranium elution from the loaded TOA impregnated polyurethane. The elution experiments were carried out by using a series of columns. Each one contained 1 g of

prepared foam TOA impregnated foam (loaded with about 380 mg uranium). Systematic calculations of the eluted uranium amounts was carried out after its analysis in the collected eluate (for each elution solution tested). TABLE 6 summarizes the obtained data, it is clearly obvious that the 1 M $\text{NaCl} - 0.1 \text{M H}_2\text{SO}_4$ elution solution is the best solution tested as an eluant for uranium from the loaded TOA impregnated foam (gave about 96% uranium elution efficiency).

TABLE 6 : Elution yields using different eluent reagents

Eluent type	Amount of uranium on the loaded foam, mg	Total eluted uranium, mg	Elution efficiency, %
1 M $\text{NaCl} + 0.1 \text{M H}_2\text{SO}_4$	380.0	371.54	96.03
1 M $\text{NaCl} + 0.5 \text{M HCl}$	381.2	263.90	68.20
0.5 M $\text{Na}_2\text{CO}_3 + 1.5 \text{CaSO}_4$	385.2	222.20	57.43
0.5 M citric acid	383.0	196.40	50.76

Figure 14 shows the isolated elution curve belongs to the 1 M $\text{NaCl} - 0.1 \text{M H}_2\text{SO}_4$ solution. From which, about 49.5 mg was eluted in the 5th eluate sample fraction about 59.6 mg in the 6th eluate sample fraction. Summation of the obtained amounts of the eluted uranium in the individual eluate sample fractions gave a total amount of 371.5 mg (represents about 96% uranium elution efficiency).

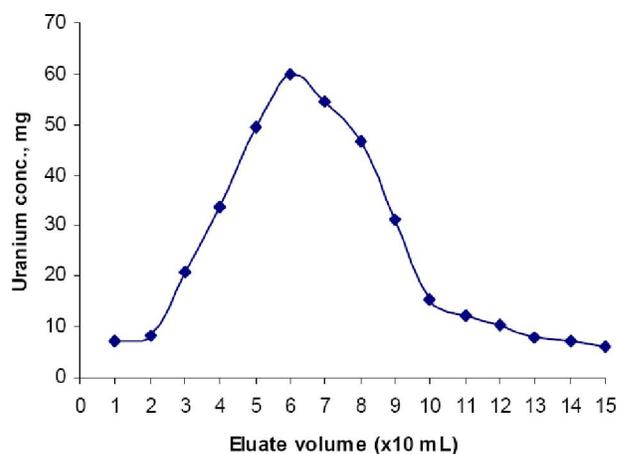


Figure 14 : Uranium elution curve of TOA impregnated polyurethane foam saturated with phosphoric acid using 1 M $\text{NaCl} - 0.1 \text{M H}_2\text{SO}_4$ as eluent.

CONCLUSIONS

The obtained results of uranium adsorption, showed

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that the solvent (TOA) impregnated foam (an extraction chromatography technique) is very efficient adsorbent media for recovery of uranium from phosphoric acid. The calculated theoretical capacity were about **1.7 g U/g** foam. The obtained low uranium adsorption efficiency (22.5% of its theoretical capacity) may be due to the adsorption competition between uranium and different ions present in crude phosphoric acid (as iron).

Using a solution composed of 1M NaCl acidified with 0.1 M H₂SO₄ for uranium elution from the loaded foam gave excellent results (reached more than 96% uranium elution efficiency).

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