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Studies on the Separation and Recovery of Uranium from Phosphoric Acid Medium Using a Synergistic Mixture of (2-Ethylhexyl)phosphonic Acid Mono 2-Ethyl Hexyl Ester (PC-88A) and Tri-n-octylphosphine Oxide (TOPO)

Suman Kumar Singh[a]; S. C. Tripathi[a]; D. K. Singh[a]
[a] Fuel Reprocessing Division, 1-Rare Earths Development Section, Bhabha Atomic Research Centre, Trombay, Mumbai, India

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Studies on the Separation and Recovery of Uranium from Phosphoric Acid Medium Using a Synergistic Mixture of (2-Ethylhexyl)phosphonic Acid Mono 2-Ethyl Hexyl Ester (PC-88A) and Tri-n-octylphosphine Oxide (TOPO)

Suman Kumar Singh, S. C. Tripathi, and D. K. Singh
Fuel Reprocessing Division, 1-Rare Earths Development Section, Bhabha Atomic Research Centre, Trombay, Mumbai, India

This paper deals with studies on the extraction of uranium(VI) from phosphoric acid medium using (2-ethylhexyl)phosphonic acid mono 2-ethylhexyl ester and tri-n-octylphosphine oxide individually as well as from their synergistic mixture. Different extraction parameters were investigated. With an increase in phosphoric acid concentration in the aqueous phase, the distribution ratio (Du) was found to decrease in all the cases. Synergism was observed when a mixture of PC-88A and TOPO was used. The synergistic mixture in the mole ratio of 4:1 (1.80 M PC-88A: 0.45 M TOPO) in xylene was found to be most suitable for uranium extraction. Among the various strip liquors used, 5% (w/v) solution of $(NH_4)_2CO_3$ was found to be the most suitable. Using a mixture of 1.8 M PC-88A and 0.45 M TOPO as the extractant system and 0.5 M ammonium carbonate as the stripping agent, uranium recovery was found to be better than 97% ± 3% in multiple contacts, (n = 2) from actual Davies Gray Waste while in case of wet phosphoric acid more than 52% ± 3% (n = 3) only could be recovered where n is the number of contacts.

Keywords acidic extractant; extraction; neutral donors; solvent composition; synergism; wet process phosphoric acid

INTRODUCTION

Nuclear power production is based on the uranium fuel cycle and thus uranium plays an important role in nuclear power generation but it has limited resources. To bridge the gap between demand and supply, its secondary resources are being explored worldwide (1,2). Natural phosphates are found to contain several tens to hundreds of parts per million of uranium, depending upon the origin of the phosphate rocks (3). Statistically, geochemical data show that sedimentary phosphate deposits of marine origin have higher uranium content than those of igneous origin. Besides the geochemical origin, the geographical locations, the type of the deposit and its degree of weathering influence the uranium content in phosphate rocks. During the acidulation of phosphate rocks in sulphuric acid for the production of wet process phosphoric acid (WPA), most of the uranium (>90%) dissolves in phosphoric acid (4). Among the various separation techniques solvent extraction has been reported to be most successful for extraction of hexavalent uranium – the form in which uranium is generally present in phosphoric acid (5–7). Among these systems, di-2 ethylhexyl phosphoric acid (D2EHPA)-tri-n-octyl phosphine oxide (TOPO) is the most popular and proven system for uranium recovery from wet process phosphoric acid (8) and is used for the extraction of uranium from wet process phosphoric acid. It is not tested for application to the other radioanalytical nuclear wastes of phosphoric acid media. In an attempt to select an alternate solvent system for uranium recovery from phosphoric acid media, various solvent systems including D2EHPA-TBP (9), n-octyldecylsulfoxide-petroleum solfoxide (10), 2,4,4-trimethylpentylphosphonic acid-neutral oxo donors (11), di (2-ethylhexyl) phosphoric acid-dibutylbutyl phosphate (D2EHPA.DBBP) (12), dinonylphenyl phosphoric acid-tri-n-octylphosphine oxide (DNPPA.TOPO) (13) have been investigated for the separation and recovery of uranium from different phosphoric acid sources. Among the organophosphorus acidic extractants, 2-ethylhexyl phosphonic acid mono 2-ethyl hexyl ester (PC-88A) has similar extraction properties to those of D2EHPA and is gaining importance in the separation of rare earths and base metals from their secondary resources. Synergistic mixtures of (2-ethylhexyl) phosphonic acid mono 2-ethylhexyl ester and octylphenyl-N,N-diisobutylcarbamoylmethyl phosphine oxide (PC-88A.CMPO) (14) and mixture of 2-ethylhexyl phosphonic acid mono 2-ethylhexyl ester and tri-n-butyl phosphate, (PC-88A.TBP) (15) have been studied for uranium recovery from phosphoric acid. PC-88A has also been investigated for the extraction of uranium from nitric acid medium (16) and

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Address correspondence to Suman Kumar Singh, Fuel Reprocessing Division, 1-Rare Earths Development Section, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India. Tel.: +91 22 25591203; Fax: +91 22 25505151. E-mail: skschapra@yahoo.co.in

hydrochloric acid medium (17). There is a need to screen a combination of alternate synergistic solvent system suitable for the separation and recovery of uranium from wet process phosphoric acid as well as from any other sources of phosphoric acid media like radio analytical waste of reprocessing facilities. Tri-n-octylphosphine oxide (TOPO) is a neutral organophosphorous extractant which is suitable for the extraction of uranium from low level sources. Since a synergistic mixture of 2-ethylhexyl phosphonic acid mono 2-ethylhexyl ester (PC-88A) and tri-n-octyl phosphine oxide (TOPO) has not been investigated for the separation and recovery of uranium from phosphoric acid media, the extraction of uranium from phosphoric acid medium using these extractants individually as well as with their synergistic mixture is the subject of the present investigation. The optimum conditions obtained during this study were also applied to the separation and recovery of uranium from actual wet process phosphoric acid (WPA) as well as from radioanalytical waste generated during analysis of uranium by the Davis Gray method.

THEORY

Acidic ligands in combination with organophosphorous neutral donors are reported to be an attractive option for the separation and recovery of uranium (VI) from acidic medium (18). One of the most important advantages of such systems is the increase in the extraction efficiency of the interest of element (19).

The solvent PC-88A, an acidic extractant, is a derivative of orthophosphoric acid. Uranium (VI) is extracted by acidic extractants in dimeric form as $UO_2(HA)_2A_2$, where A represents the derivative of alkyl ($-OC_8H_{17}$) and phosphoryl (P=O) groups of typical organophosphorus acidic solvents and where HA is the organophophorus acidic solvent itself (20). The uranium-solvent complex will be either monomeric or dimeric depending on the uranium loading level of the carrier. The following reactions were suggested for cases of low and high level uranium loading conditions (21).

For a high level metal loading (monomer formation)

$$UO_{2\,(aq)}^{++} + nHA_{(org)} \rightleftharpoons (UO_2A_n)^{2-n}_{(org)} + nH^+_{(aq)} \qquad (1)$$

For low level uranium loading (dimer formation)

$$UO_{2\,(aq)}^{++} + n(HA)_{2\,(org)} \rightleftharpoons UO_2(A.HA)_{n(org)} + nH^+_{(aq)} \qquad (2)$$

where, $n = 2$–3.

The different phosphate salts of uranium present in H_3PO_4 include $UO_2(H_2PO_4)_2$, $UO_2(H_2PO_4)_2.H_3PO_4$ or $UO_2(H_2PO_4)n^{2-n}$.TOPO, being a neutral donor, forms a complex with U(VI) through coordination with the oxygen of the phosphoryl group and does not release any proton as a result of dissociation and therefore the extraction is not affected by the acidity of the solution as in the case of the acidic extractant (22).

EXPERIMENTAL

Reagents

Commercial grade 2-ethylhexyl phosphonic acid mono 2-ethylhexyl ester (PC-88A) (purity >95%) from Daihachi Chemical Industry Co. Ltd., Japan, was used as supplied. Tri-n-octyl phosphine oxide (TOPO) supplied by Fluka, Switzerland, was used as such.

The stock solution of uranium (10 g/L) was prepared from uranyl nitrate hexahydrate and converted into phosphoric acid medium using the method reported earlier (23). Suitable aliquots from this stock solution were used to prepare feed during the batch studies. ^{233}U separated and purified from THOREX streams was used as radio tracer to follow the extraction behavior of uranium (24). All other reagents used were of analytical grade.

Analysis

Uranium in the aqueous and organic phases before and after equilibration was assayed by estimating ^{233}U α counts using an α scintillation counter with a Ag – activated ZnS detector. The efficiency of the detector standardized using ^{239}Pu was $30 \pm 2\%$. Generally the mass balance for all the batch experiments was found to be within $\pm 5\%$. All of the experiments were carried out at room temperature, $25°C \pm 2°C$.

Batch Experiment

Suitable aliquots from the stock solution of uranium were used to prepare feed solutions during the batch extraction studies. In these studies, a fixed volume of the aqueous phase (generally 2 to 20 mL) at the desired concentration of H_3PO_4 and containing a known concentration of uranium spiked with tracer activity of ^{233}U was contacted with equal volume of the extractant.

To optimize the equilibration time the batch extraction was carried out separately for different intervals of time, varying up to 1 h using the desired organic phase at an organic-to-aqueous phase ratio of 1:1. The feed solutions used in these studies were spiked with tracer activity of ^{233}U that contained 300 mg/L uranium at 0.5 M H_3PO_4. After contact the phases were separated and assayed for alpha activity.

Under similar feed conditions the extraction of uranium was also studied using the solvent mixture of varying concentrations of PC-88A and TOPO in xylene. Preliminary experiments were carried out using 0.15 M PC-88A and 0.1 M TOPO separately. The acidity of aqueous feed was varied from 0.5 M to 5.0 M H_3PO_4. The aqueous phase concentrations of uranium in these cases were maintained at 300 mg/L during these experiments the phase ratio was 1:1 and equilibration time was 30 minutes.

Experiments were also carried out to optimize the solvent composition by studying the effect of mole ratio of the components on the uranium distribution ratio.

In a separate set of experiment the extraction behavior of uranium was studied using 0.15 M PC-88A and 0.01 M TOPO in commonly available diluents, viz., kerosene, xylene, toluene, benzene, hexane, chloroform, and carbon tetrachloride. The extraction of uranium using the solvent mixture of PC88A and TOPO was also studied from an aqueous phase containing different concentration of uranium in the range 0.3–10 g/L at 5 M H_3PO_4.

The selection of a reagent for uranium stripping from the composite organic phase was carried out using commonly used stripping agents, viz., HNO_3 (8 M), HCl (12 M), H_2SO_4 (10 M), $(NH_4)_2CO_3$ (2 M), citric acid (1 M), urea (3 M), sodium salt of EDTA (0.01 M), and water. After assaying the uranium in both phases by radiometry, using distribution ratio values (D) the percentage extraction and synergistic coefficient (19) were calculated using the following equations

$$\text{Percentage of extraction} = \frac{100 \times D}{D + 1} \qquad (3)$$

$$\text{Synergistic coefficient (S.C.)} = \log \frac{D_{1,2}}{D_1 + D_2} \qquad (4)$$

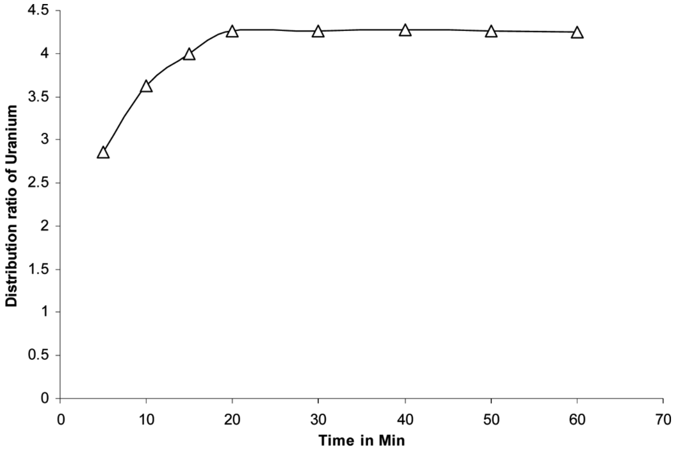
where $D_{1,2}$ is the distribution ratio of uranium using the synergistic mixture during extraction and D_1, D_2 are the distribution ratios of uranium using the individual extractant.

The experiments were carried out to study the extraction and recovery of uranium from the WPA sample as well as from analytical waste generated during uranium analysis by the Davies-Gray method (25). In both cases, equal volumes (generally 2 mL) of aqueous feed and of the synergistic mixture of PC-88A + TOPO (Mole ratio of 4:1) were equilibrated. The same test run was carried out for multiple contacts using a fresh extractant mixture each time.

RESULTS AND DISCUSSION

Kinetic Studies

The extraction behavior of uranium by a mixture of PC-88A and TOPO as a function of time was studied and the results are given in Fig. 1. These results indicate that a contact time of 20 minutes is enough to reach equilibrium. Based on these results a contact time of about 30 minutes was maintained in all the extraction experiments so as to ensure that equilibrium has been attained.



Experimental Conditions

Conc. of uranium in feed : 300 mg/L,
Extractants : 1.80 M PC-88A + 0.45 M TOPO in xylene
Contact time : 30 min. each
Phase ratio : 1:1 in each contact

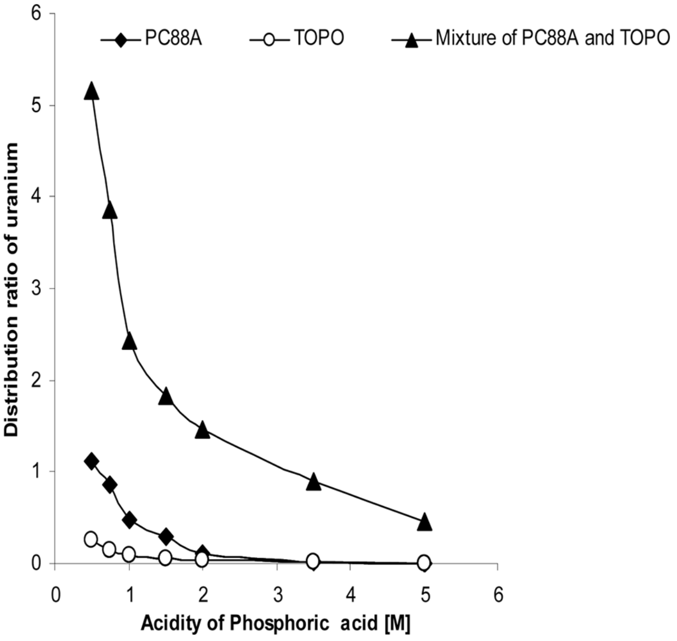
FIG. 1. Distribution ratio of uranium as a function of time.

Synergistic Effect

Table 1 gives the data on the extraction behavior of uranium from phosphoric acid using varying concentrations of the individual extractants. The results show low extraction of uranium by PC-88A ($Du \sim 10^{-1}$) which increases with increasing concentration of the extractant. The extraction of uranium by TOPO is observed to be lower (by an order of magnitude) under the experimental conditions and as increase in Du values is not remarkable with increasing concentration especially above 0.1 M of TOPO.

TABLE 1
Extraction of uranium using varying concentration of PC88A and TOPO Experimental conditions: Conc. of uranium in feed: 300 mg/L, Conc. of H_3PO_4 in feed: 5 M, Contact time: 30 min

Distribution ratio of uranium			
PC-88A in xylene		TOPO in xylene	
[PC-88A] (M)	D_U	[TOPO] (M)	D_U
0.03	0.06	0.01	0.024
0.09	0.16	0.02	0.029
0.15	0.47	0.05	0.034
0.30	0.57	0.10	0.038
0.45	0.72	0.20	0.039
0.60	0.86	0.30	0.040
0.90	1.09	0.50	0.040



Experimental Conditions

Conc. of uranium in feed	: 300 mg/L,
Extractants	: 1.80 M PC-88A + 0.45 M TOPO in xylene
Contact time	: 30 min. each
Phase ratio	: 1:1 in each contact

FIG. 2. Uranium distribution ratio as a function of phosphoric acid concentration.

Figure 2 and Table 2 represent the data on the distribution ratio of uranium as a function phosphoric acid concentration for the extraction of uranium(VI) with PC-88A and TOPO individually and with their mixture. The concentration of extractants has been chosen arbitrarily. D values decrease with an increase in the concentration of phosphoric acid for all the three extraction systems.

Decrease in the distribution ratio of uranium by TOPO may probably be due to the coextraction of acid/water in the organic phase. When PC-88A is used as an extractant, Du decreased with an increase in acid concentration which explains the cation-exchange behavior of PC-88A. In the case of TOPO alone, even though the D values obtained were very low, the trend is similar to that of PC-88A, which may be due to the extraction of acid instead of uranium.

When a mixture of PC-88A and TOPO is used for extraction of uranium, significant improvement in the distribution ratio indicates the occurrence of synergism, which is verified by positive values of the synergistic coefficient. This synergistic effect may presumably be due to the more hydrophobic nature of the extracted species caused by enhanced dehydration of uranium by the neutral extractant, TOPO. Such a mechanism has been reported in literature when D2EHPA and TBP are used for uranium extraction from H_3PO_4 medium (9).

Optimization of Solvent Composition

Separate test runs were carried out to study the effect of mole ratio (PC-88A to TOPO) on the D value of U(VI) from 5.0 M phosphoric acid at phase ratio (O/A) = 1. In these experiments extractions were carried out by varying the concentration of either extractant while keeping the concentration of other constant. The other parameters were similar to those described above. From the data presented in Table 3, it is evident that with an increase in concentration of PC-88A at constant TOPO concentration and with an increase in TOPO concentration at constant PC-88A concentration, the D value increased and reached a maximum at a mole ratio (PC-88A:TOPO) of 4 and then decreased. At lower concentrations of TOPO, the increase

TABLE 2
Extraction of uranium from varying concentration of H_3PO_4 using PC-88A, TOPO and their mixture

Conc. of uranium in feed : 300 mg/L,
Conc. of H_3PO_4 in feed : 0.5 M to 5 M
Contact time : 30 minutes

$[H_3PO_4]$ in feed (M)	Extraction using 0.15 M PC-88A in xylene D_U	Extraction using 0.1 M TOPO in xylene D_U	Extraction using a mixture of 0.15 M PC-88A and 0.1 M TOPO in xylene Du	Synergistic coefficient S.C.
0.50	1.12	0.251	5.16	0.575
0.75	0.86	0.141	3.86	0.586
1.0	0.47	0.087	2.44	0.641
1.5	0.29	0.061	1.83	0.717
2.0	0.11	0.031	1.47	1.018
3.5	0.024	0.015	0.90	1.363

TABLE 3
Effect of variation in concentration of either of the extractants on extraction of uranium

Conc. of uranium in feed : 300 mg/L
Conc. of H_3PO_4 in feed : 5 M

Composition of extractants mixture		Extraction of uranium using a mixture of extractants Du
[PC88A] in xylene (M)	[TOPO] in xylene (M)	
0.5	0.10	1.813
1.0	0.10	2.867
1.2	0.10	3.185
1.5	0.10	3.428
1.8	0.10	3.431
2.0	0.10	3.232
2.2	0.01	3.123
1.80	0.10	3.198
1.80	0.20	3.432
1.80	0.30	3.868
1.80	0.40	4.281
1.80	0.45	4.137
1.80	0.50	4.026
1.80	0.55	3.983

TABLE 4
Effect of diluents on the extraction of uranium from phosphoric acid medium using a synergistic combination of PC-88A and TOPO

Conc. of uranium in feed : 300 mg/L
Conc. of H_3PO_4 in feed : 0.5 M to 4.5 M
Extractant mixture : 0.15 M PC88A + 0.1 M TOPO
Diluents : Different diluents

[H_3PO_4] (M)	Distribution ratio of uranium (Du)				
	Xylene	Kerosene	Toluene	Benzene	Chloroform
0.50	5.16	5.12	2.67	219	2.36
0.75	3.86	3.78	1.52	1.34	1.38
1.0	2.44	2.41	0.79	0.73	0.76
1.5	1.83	1.79	0.31	0.24	0.28
2.0	1.47	1.42	0.11	0.09	0.01
3.5	0.90	0.88	0.009	0.005	0.007
4.5	0.46	0.45	0.004	0.001	0.002

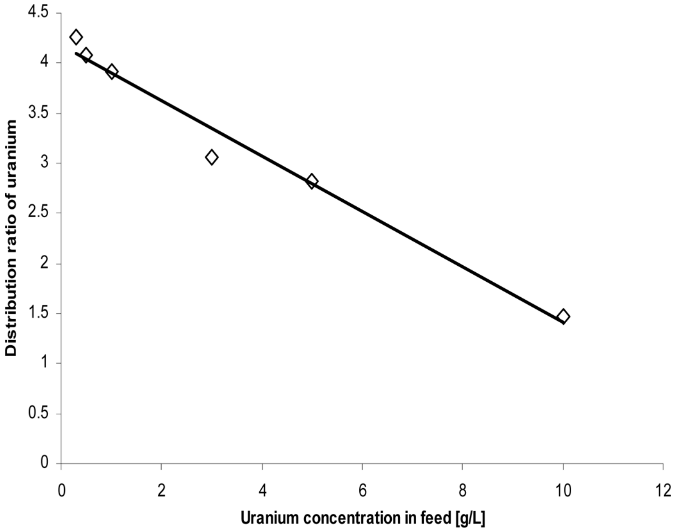
in D_U can be explained by the fact that the extraction is mainly controlled by the concentration of PC-88A. At higher concentrations of TOPO, the aqueous phase complexation is controlled by the phosphoric acid and the organic phase complexation is controlled by the concentration of TOPO.

The gradual increase in D_U indicates the influence of synergism with increasing concentration of TOPO. The increase in extraction can therefore be attributed to the extraction of uranium due to the formation of a synergistic species. At higher concentration levels of TOPO, synergism is attributed to the possible effect of TOPO on the solvent polarities. The results depicted in Table 3 suggest that an optimum molar ratio of PC-88A to TOPO is 4 for the maximum extraction of U(VI) under comparable extraction condition.

This optimum mole ratio of 4 also indicates that the extracted species of U(VI) from phosphoric acid with the synergistic mixture of PC-88A and TOPO contains two molecules of the dimeric form of PC-88A (H_2A_2 is the dimer form of PC-88A in non-polar diluents) and that one molecule of TOPO is associated with it. Thus the structure of the extracted species may be shown as $UO_2(HA_2)_2.TOPO$.

Effect of Diluents

The effect of diluents on extraction of uranium from phosphoric acid medium was studied using the synergistic mixture (1.8 M PC-88A + 0.45 M TOPO) discussed above. The results presented in Table 4 indicate that xylene and kerosene, with distribution ratios of 5.16 and 5.12 respectively, from 0.5 M H_3PO_4 feed, are equally suitable diluents



Experimental Conditions

Conc. of uranium in feed	: 300 mg/L,
Extractants	: 1.80 M PC-88A + 0.45 M TOPO in xylene
Contact time	: 30 min. each
Phase ratio	: 1:1 in each contact

FIG. 3. Distribution ratio of uranium as a function of uranium concentration in feed [g/L].

for the extraction of uranium from phosphoric acid medium. So either of these two, generally xylene, will be used for further studies. Benzene, carbon tetrachloride, and hexane exhibit lower distribution ratios than the preferred diluents. This may be attributed due to the difference in their structural properties. The extraction is affected by the polarity and the structural properties of the diluents as it affects the ion association and solvation of a metal ion with the extractants.

The free energy of formation is unfavorable for the transfer of a charged species from a solvent of high dielectric constant such as water to one of low dielectric constant like common aliphatic and aromatic diluents. In many instances, the dielectric constant is considered as the primary solvent property that governs the partition coefficient in a series of solvents.

Effect of Uranium Concentration in Feed

The synergistic mixture of 1.80 M PC-88A + 0.45 M TOPO in xylene was used to extract uranium from 5.0 M H_3PO_4 feed solution containing different concentrations of uranium varying from 0.3–10 g/L. This is the maximum concentration range of uranium that is expected in various secondary resources. The results presented in Fig. 3 indicate that the distribution ratio of uranium decreased with an increase in uranium concentration of the aqueous feed. This decrease in D_U can be attributed to the decreased free solvent concentration at equilibrium during extraction.

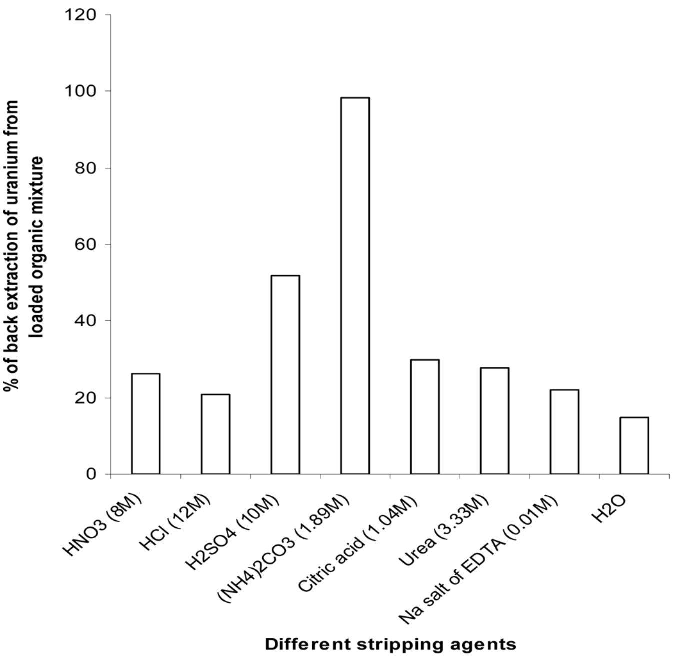
Mathematically, in turn, the effective extractant concentration can be calculated using equation (5), (18)

$$[H_2A_2]F = [H_2A_2]i - n[Mo] \qquad (5)$$

where $[H_2A_2]_F$ = the free extractant concentration and H_2A_2 represents the dimeric form of PC-88A, $[H_2A_2]_i$ = the the initial concentration of PC-88A, n = charge on metal ion (UO_2^{2+}), Mo = Metal concentration in organic phase.

Back Extraction of Uranium

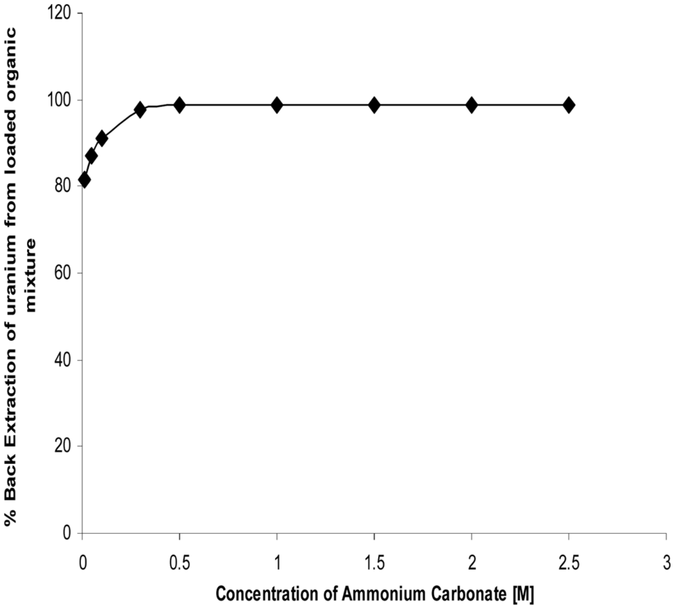
The uranium-loaded composite organic phase was used to study the stripping behavior of uranium using commonly available stripping agents. Results of stripping using these reagents are given in Fig. 4. Among the various reagents used, 2.0 M ammonium carbonate was found to be



Experimental Conditions

Conc. of uranim in composite organic phase	: 100 mg/L)
Organic: aqueous phase ratio	: 1:1 in each contact
Contact time	: 30 min. each

FIG. 4. Back extraction of uranium from a synergistic system of 1.80 M PC-88A + 0.45 M TOPO in xylene by different stripping agents.



Experimental Conditions

Extractant composition	: 1.80 M PC-88A+0.45 M TOPO
Conc. of uranium in composite organic phase	: 100 mg/L
Organic: aqueous phase ratio	: 1:1 in each contact
Contact time	: 30 min. each

FIG. 5. Optimization of the concentration of $(NH_4)_2CO_3$ as stripping agent for uranium from the loaded synergistic organic phase.

TABLE 5
Comparison of distribution ratios of uranium from phosphoric acid medium using different synergistic solvent systems

Conc. of uranium in feed : 300 mg/L
Conc. of H_3PO_4 in feed : 0.5 M to 4.5 M
Extractant mixture : 0.15 M PC88A + different neutral donors
Diluents : xylene

H_3PO_4 [M]	Distribution ratio of uranium using different synergistic solvent combination PC-88A-CMPO	PC-88A-TBP	PC-88A-TOPO
0.5	2.23	1.68	5.16
0.75	1.17	1.29	3.86
1.0	0.678	0.931	2.44
1.5	0.426	0.611	1.83
2.0	0.224	0.175	1.47
3.5	0.160	0.062	0.90
4.5	0.060	0.026	0.42

most effective and could strip uranium quantitatively in a single batch contact. It is evident that the stripping of U(VI) by various reagents followed the order: $(NH_4)_2CO_3 > H_2SO_4 > HNO_3 > HCl >$ urea > EDTA > citric acid. The concentration of ammonium carbonate was optimized in a separate experiment where uranium from the composite organic phase was stripped using varying concentrations of ammonium carbonate (0.1–2.5 M). The results presented in Fig. 5 show that even 0.5 M concentration of ammonium carbonate is enough to strip uranium quantitatively from the organic phase in a single batch contact.

COMPARISION WITHOTHER SYNERGISTIC SYSTEMS

The various synergistic solvent systems employed for the separation and recovery of uranium from phosphoric acid media are compared. The distribution behavior of uranium from actual wet process phosphoric are investigated in detail using D2EHPA + TOPO solvent system and reported uranium distribution ratio are 2.2, 4.4 and 5.8 from 6.0, 5.3, and 4.8 M H_3PO_4 media (2).

The other synergistic solvent systems reported recently (Singh et al. 2009), for the separation and recovery of uranium from phosphoric acid media are compared Table 5. The observed distribution ratios for uranium from phosphoric acid media indicates that the PC-88A.TOPO system is much better than other two studied systems (PC-88A.-TBP, PC-88A.CMPO) for the selected range of acidities of H_3PO_4. At 0.5 M H_3PO_4 acidity the observed distribution ratios for uranium are 2.23, 1.68, and 5.16 for PC-88A.CMPO, PC-88A.TBP, and PC-88A.TOPO respectively. This may be attributed to the high basicity of the TOPO in the synergistic solvent system.

APPLICATION

The optimized solvent composition (1.80 M PC-88A 0.45 M TOPO) in xylene was tested for uranium extraction for an actual wet process phosphoric acid supplied by the Uranium Extraction Division of this center as well as from radioanalytical waste generated in the reprocessing facility of this center during uranium analysis by the Davies-Gray method. The results presented in Table 6 indicate that more than 52% uranium was extracted from wet process phosphoric acid in three contacts using fresh organic each time while more than 97% uranium was extracted from the Davies-Gray waste only in two contacts. In both the cases

TABLE 6
Extraction of uranium from WPA and Davies. Gray analytical waste using synergistic mixture of PC-88A and TOPO

Conc. of uranium in feed : 300 mg/L
Extractants system : 1.80 M PC-88A + 0.45 M TOPO in xylene/kerosene
Contact time : 30 min. each

Details of the feed used	$[H_3PO_4]$ (M)	Percentage extraction In multiple contacts I	II	III	Cumulative extraction (%)	Stripping of uranium from loaded organic phase (%)
WPA sample	5.12	18.74	21.63	24.69	52.04	98.59
Analytical Waste of Davies-Gray method $[H_3PO_4 + H_2SO_4]$ method Feed composition $\{[U^{(VI)}]$ 197 mg/L, $[Fe^{++}]$ 373 mg/L, $[Mo^{(VI)}]$ 22 mg/L, $[K^{+}]$ 119 mg/L, $[Cr^{(III)}]$ 159 mg/L$\}$	2.5–2.6 M	83.26	86.19	–	97.69	98.87

the quantitative recovery of uranium was achieved in a single contact using 0.5 M ammonium carbonate as the stripping agent.

CONCLUSIONS

Extraction of uranium(VI) decreased with increase in phosphoric acid concentration in solution for all the systems tested. The order being: PC88A + TOPO > PC88A > TOPO. Synergism was observed with a solvent mixture of PC-88A and TOPO. With a low concentration of H_3PO_4 and with a phase ratio of 1:1 when a mixture of PC-88A and TOPO (mole ratio 4:1) is used as extractant system, a significant improvement in the extraction of uranium is observed and that is due to the synergistic effect. A synergistic solvent mixture PC88A in combination with TOPO demonstrated the feasibility of using this extractant combination for the efficient recovery of uranium from phosphoric acid medium. Xylene was found to be most suitable diluent for this system. Out of various stripping agents tested, 0.5 M $(NH_4)_2CO_3$ can be used efficiently for the quantitative stripping of uranium from the loaded extract. It was observed that this synergistic mixture of solvents is very promising for the separation and recovery of uranium from analytical waste generated in radioactive laboratories.

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