Selective separation of uranium from xenotime-bearing ferruginous sandstone of Southwestern Sinai, by using carbonate leaching

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ABSTRACT

Besides being a xenotime-bearing, the ferruginous sandstone of Southwestern Sinai and which belongs to the Adediya Formation of the Cambrian age has also been proven to be relatively uraniferous. A technological sample of this ore material has been collected from Wadi El Sahu area and was found to assay up to 15.43% RE_2O_3 and 0.071% U. The latter involves alkali agitation leaching of the ore material and where the studied optimum conditions includes 90 g/l Na_2CO_3 concentration, 30 g/l $NaHCO_3$ concentration at a S/L ratio of 1/2 for 4 hrs agitation time at room temperature and using an ore grain size ground to -200 mesh. Under these conditions, a uranium leaching efficiency of 97.2 % has been obtained. From the obtained leach liquor, U was separated through two techniques; namely direct precipitation and a prior application of anion exchange resin.
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KEYWORDS

Separation;
Uranium;
Xenotime;
Carbonate leaching.

INTRODUCTION

Exploration of uranium in Wadi El Sahu of Southwestern Sinai (East of Abu Zenima) has revealed that two major mineralizations are present. The latter are indeed associated with thick sedimentary succession while belong to Cambrian and lower Carboniferous in age. While the former involves sandstones, siltstones and conglomerates, the latter involves Um Bogma Formation which includes Mn-Fe ore lenses with mottled shale, siltstone and sandy dolostone at the top. The mineralization associated with Adediya Formation is essentially a xenotime-bearing ferruginous sandstone which also includes a relatively moderate U concentration which is mainly associated with the iron oxides and clay minerals[1]. From the ferruginous sandstone beds of Wadi El Sahu, a technological sample was collected to study the recovery of U and REEs and in which these metal values assay 0.071% U and up to 15.43% RE_2O_3.

Depending upon the nature of the uranium pregnant solution and its concentration, several techniques could be used for its to recovery uranium. These techniques involve mainly direct precipitation, ion-exchange resins and organic solvents[2]. Thus, for a uranium concentration greater than 1 g U/l solvent extraction is preferred while for a concentration below 1 g U/l ion exchange resin would be the best whereas direct precipitation requires indeed a much higher uranium concentration (several tens of grams U per litre).

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As a matter of fact, anion exchange resins are actually quite suitable to extract and concentrate uranium from its low-grade pregnant solutions due to their ability to selectively adsorb uranium from either sulfate or carbonate leach liquors. This is due to the fact that uranium is present in such liquors as anionic complexes. After uranium is loaded upon the resin, it could be eluted by a suitable salt solution to obtain a relatively highly pure concentrated uranium eluates.

Xenotime, the RE phosphate mineral, is actually one of the three principal RE minerals together with monazite and bastanasite, however, its REEs belong mainly to the heavy elements contrary to these two minerals. On the other hand, xenotime is a refractory mineral which requires adequately severe conditions for its breakdown. According to Viyayalakshmi et al.[3], its acid breakdown involves attack or leaching with concentrated H_2SO_4 (98%) at 250 to 300^{0}C for 1 to 2 hours. This attack is considered economic for the working ore material since its xenotime content exceeds 10% xenotime. Alternatively, xenotime concentrate can be processed by fusion of the finely ground ore with molten caustic soda at 400^{0}C[4] or else by roasting with Na_2CO_3 at 900^{0}C for several hours[5].

Alkali carbonate (sodium or less commonly ammonium) is sometimes used for uranium leaching from its ores that are high in carbonate gangue minerals like calcite, dolomite, etc. This depends on the fact that the carbonate anion forms with uranium stable soluble uranyl carbonate complex $[UO_2(CO_3)_n]^{2-2n}$. It can be applied to both primary and secondary mineral deposits, however after oxidation of the former. Alkali carbonate leaching has several important advantages over acid leaching including its selectively where comparatively pure solutions are readily obtained beside its non-corrosive nature. Also, the consumption of the reagent by the ore is low and uranium can be readily recovered from the leach liquors. Finally, the carbonate solutions can be regenerated for further leaching recycle. However, there are some limitations to the use of carbonate leaching due to its mild nature so that some uranium minerals are not solubilized by carbonate leach solutions. Moreover it requires fairly fine grinding of the ore in order to obtain reasonable reactions rates. Alternatively, carbonate leaching could be performed under relatively high pressure and temperature in suitable au-

toclaves[6].

In alkali carbonate leaching, uranium should be also in its hexavalent oxidation state. Pyrolusite and iron are not effective oxidants in the alkaline leaching circuit due to the insoluble nature of Mn or iron carbonate. Generally, sodium chlorate is used in carbonate leaching circuit. The carbonate reaction with U^{6+} can be represented by the following reaction:

$$UO_3 + 3Na_2CO_3 + H_2O \rightarrow Na_4UO_2(CO_3)_3 + 2NaOH$$
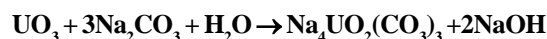
Sodium hydroxide resulting in the above reaction would increase the solution pH; a matter which would lead to uranium precipitation. Therefore in order to prevent pH rising to a value at which reprecipitaion of uranium will occur, sodium bicarbonate is used to buffer the hydroxide formed[6] and the overall reaction can thus be represented as follows:

$$UO_2 + 1/2O_2 + Na_2CO_3 + 2NaHCO_3 \rightarrow Na_4UO_2(CO_3)_3 + H_2O$$

Finally it might be interesting to mention that presence of sulfide (e.g. pyrite) or sulfate minerals (e.g. gypsum) is harmful for carbonate leaching where high consumption of the relatively expensive sodium ion would occur. According to Thunaes[7], the sulfide content should not exceed 0.4 - 0.5% equivalent sulfur.

EXPERIMENTAL

Material characterization

The collected technological sample representing the ferruginous sandstone of the Adediya formation of Wadi El Sahu was first subjected to complete chemical analysis of the major oxides as well as for some interesting trace elements besides the tenor of the economic metal values. On the other hand, for mineral identification, the constituent mineral grains have properly been separated via the heavy liquid bromoform before being subjected to XRD analysis.

Alkaline agitation leaching procedure of uranium

For studying the leaching of uranium from the working xenotime-bearing ferruginous sandstone ore material, agitation leaching was applied. In this type of leaching, a weighed ore sample (5 gm) is agitated in Na_2CO_3 and $NaHCO_3$ solutions of different concentrations and in different S/L ratios at different temperatures for different time periods. The main relevant agitation leach-

ing conditions were studied including the concentration of sodium carbonate alone, the S/L ratio, the leaching time and temperature besides the effect of sodium bicarbonate addition as well as the ore grain size. At the end of each leaching experiment, the ore slurry was filtered, the residue was properly washed and the obtained leach liquor and washings were completed to a proper volume for U analysis.

Analytical procedures

Chemical analysis

For the determination of the chemical composition, about 50 g sample weight was separated by quartering from the finely crushed representative sample before being ground down to – 200 mesh size. The pulverized sample was then analyzed using the conventional wet chemical procedures given by Shapiro and Bannock[8] where SiO_2, Al_2O_3, TiO_2 and P_2O_5 were spectrophotometrically analyzed. While both Na and K were determined by flame photometry and iron oxide was determined titrimetrically using sulfosalicylic acid as an indicator. Also, CaO and MgO were determined titrimetrically through murexide and black T indicators respectively. On the other hand, the analyzed trace elements including Cr, Ni, Cu, Zn, Zr, Pb, Sr and Ga besides Mn were estimated by the atomic adsorption technique using Unicam 969 model spectrometer fitted with auto gas box.

For the working metal values, $\Sigma REEs$ were spectrophotometrically determined in the original sample and in the different stream solutions using arsenazo (III)[9] while the prepared RE_2O_3 final product, XRF was used. On the other hand, uranium was volumetrically analyzed in the original sample and in the different stream solutions using ammonium metavanadate in the presence of diphenyl sulfonate indicator after its previous reduction by ammonium ferrous sulfate[10].

Uranium extraction procedures from alkaline medium

The study of the leaching characteristics of U from Wadi El Sahu ferruginous sandstone ore material was performed by alkaline agitation leaching technique. This is followed by the proper uranium recovery from the obtained carbonate leach liquor.

i) Direct precipitation

In this technique, U was directly precipitated using 10% NaOH solution till a pH of 7.5 followed by carbonate purification of the precipitate.

ii) Anion exchange recovery

In anion exchange resin, U was selectively recovered from the obtained soaking leach liquor using Amberlite IRA-400 followed by its eluation with acidified NaCl solution. The obtained U eluate was then subjected to its precipitation as sodium di-uranate ($Na_2U_2O_7.2H_2O$) via pH adjustment using 10% NaOH solution until pH 7.5.

Extraction procedures of REEs

The uranium-free ore residue has indeed been subjected to pug leaching for xenotime breakdown using concentrated H_2SO_4 (98%) at 250°C for 2 hrs. followed by water leaching of REEs. The latter were then recovered by their direct precipitation using oxalic acid as REEs oxalates.

Mineralogical identification

A part of the technological sample was also subjected to heavy mineral separation technique which involved disaggregation of the mineral grains by soaking in water followed by proper declaiming and drying. The deslimed dry sample was then screened using a mechanical shaker and where the size fraction – 1 to + 0.062 mm (about 18 to 230 mesh) was subjected to heavy liquid separation using bromoform (Sp.gr. 2.81). The mineral grain constituents of the obtained heavy fraction were picked under the binocular microscope and subjected to mineralogical identification by means of XRD.

RESULTS AND DISCUSSION

Material characteristics

Results of the average major chemical composition of the working Wadi El Sahu technological sample are given in TABLE 1. From the latter, it is clearly evident that besides 15.43% RE_2O_3 and 7.04% P_2O_5 (xenotime constituents), the ore is mainly composed of SiO_2, Al_2O_3 and, Fe_2O_3 and to a much lesser extent of TiO_2, MgO, CaO, Na_2O, K_2O and P_2O_5. The silica content thus attains 42.45% while Al_2O_3 and Fe_2O_3 assayed 8.5% and up to 20.00% respectively. While CaO and MgO assay of 0.80% and 0.67% respec-

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tively, Na_2O and K_2O attain only 0.20 and 0.45% respectively. On the other hand, analysis of uranium and some trace elements in the working ferruginous sandstone sample indicated that U amounts to 0.071% while Pb and Sr attain about 0.15% and 0.66% respectively (TABLE 2).

TABLE 1 : Chemical composition of Wadi El Sahu ferruginous sandstone ore material

Major constituent	Wt.,%	Major constituent	Wt.,%
SiO_2	42.45	MgO	0.67
TiO_2	0.56	MnO	0.05
Al_2O_3	8.50	Na_2O	0.20
Fe_2O_3	20.00	K_2O	0.45
RE_2O_3	15.43	P_2O_5	7.04
CaO	0.80	L.O.I*	2.50
Total			98.65

L.O.I.*: loss of ignition

TABLE 2 : Analytical assay of U and some trace elements of Wadi El Sahu ferruginous sandstone ore material

Trace element	Conc.,ppm	Trace element	Conc.,ppm
Cr	153	U	710
Ni	94	Zn	232
Zr	646	Cu	9
Pb	1475	Sr	6599
Ga	14		

As mentioned above, mineral separation techniques involving the heavy liquid bromoform have been applied upon a part of the working technological sample. The obtained heavy mineral fraction was subjected to XRD analysis. The latter has indicated that the princi-

pal mineral constituents involve quartz (SiO_2), hematite (Fe_2O_3) and kaolinite $Al_2Si_2O_5(OH)_4$ together with xenotime (YPO_4) whose REEs belong mainly to the heavy species (Figure 1).

It is worthy to mention herein that the ferruginous sandstone ore material does not show any uranium mineral in a manner to suggest that the analyzed uranium content (0.071%) is most probably adsorbed upon the iron oxides and clay minerals together with a quite small amount of rare earths. On the other hand, it has to be indicated herein that the xenotime mineral present in the working ore material is devoid of any U or Th as has previously proved by Amer et al.[11].

i) Effect of Na_2CO_3 concentration

To study the effect of Na_2CO_3 conc. upon the leaching efficiency of uranium from the studied ore material, a set of leaching experiments was performed using different concentrations of Na_2CO_3 ranging from 15 to 105 g/l. The other leaching conditions were fixed at room temperature (25°C) for 4 hrs in a S/L ratio of 1/2 and using the ore ground to -200 mesh size. The obtained leaching efficiencies are plotted in Figure 2

From the obtained data, it is clear that the leaching efficiency of U increases from 14 to 69 % by increasing the concentration of Na_2CO_3 from 15 to 90 g/l respectively. Further increase in the carbonate concentration to 105 g/l has an adverse effect on U leaching efficiency which was decreased to 64 %. This decrease is most probably due to the generation of OH⁻ during leaching; a matter which would result rising in pH to a point where diuranate would precipitate. The expected reactions are as follows:
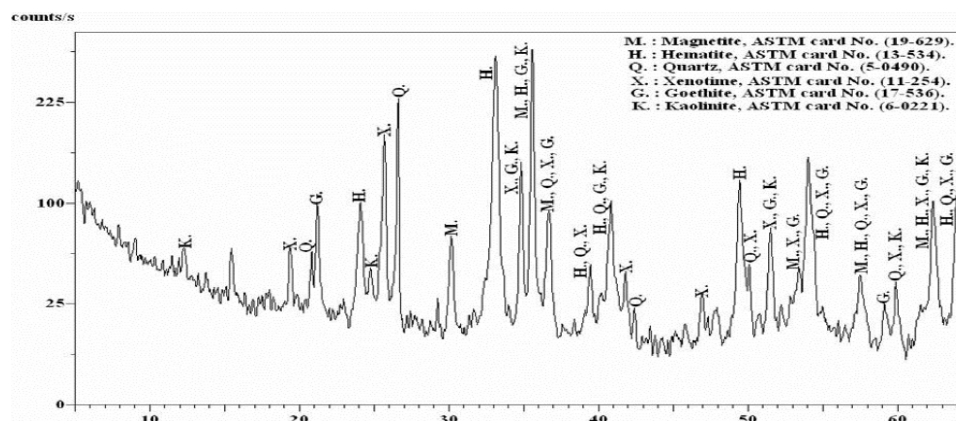

Figure 1 : XRD pattern of the main mineral constituents of the obtained bulk heavy fraction of Wadi El Sahu ferruginous sandstone ore material
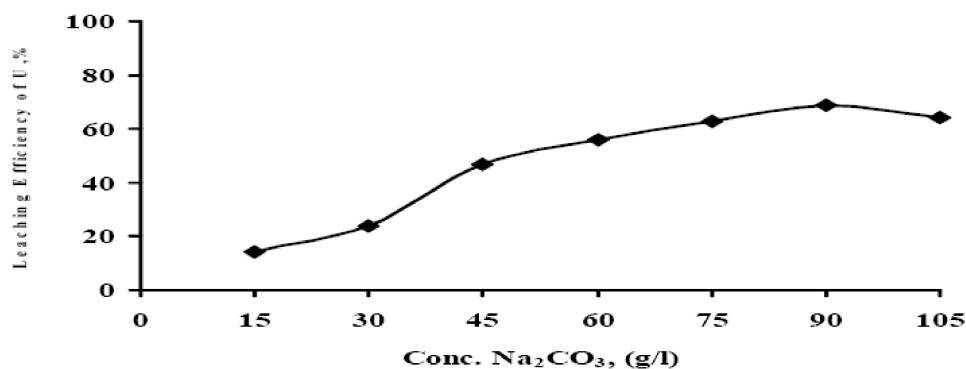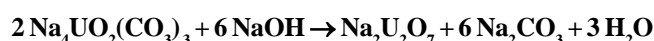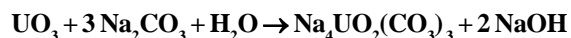
Figure 2 : Effect of Na$_2$CO$_3$conc. upon leaching efficiency of U from El Sahu xenotime-bearing ferruginous sandstone ore material

$$UO_3 + 3\,Na_2CO_3 + H_2O \rightarrow Na_4UO_2(CO_3)_3 + 2\,NaOH$$

$$2\,Na_4UO_2(CO_3)_3 + 6\,NaOH \rightarrow Na_2U_2O_7 + 6\,Na_2CO_3 + 3\,H_2O$$

Therefore, it can be concluded that a Na$_2$CO$_3$ concentration of 90 g/l would be considered as a sufficient concentration for about 70% U leaching from the working ore material under the applied conditions.

ii) Effect of solid/liquid ratio (S/L)

The effect of S/L ratio upon the leaching of uranium from the ore material under consideration was studied from the ratio 1/1 to 1/2.5 when applying Na$_2$CO$_3$ conc. of 90 g/l, 4 hrs as leaching time at room temperature

(25°C) and using the ore ground to -200 mesh size. Data of the obtained leaching efficiencies plotted in Figure 3.

From the obtained results, it can be concluded that the leaching efficiency of uranium increases with increasing the S/L ratio from 1/1 to 1/2 where the corresponding leaching efficiencies of uranium increase from 22 to 69 % respectively. Further increase in S/L ratio to 1/2.5 had an adverse effect on U leaching efficiency which decreased to 65 %. This decrease may be interpreted as being due to re-precipitation of uranium by the formation of NaOH and thus a S/L ratio of 1/2 would be considered as an optimum value for 69 % uranium leach-
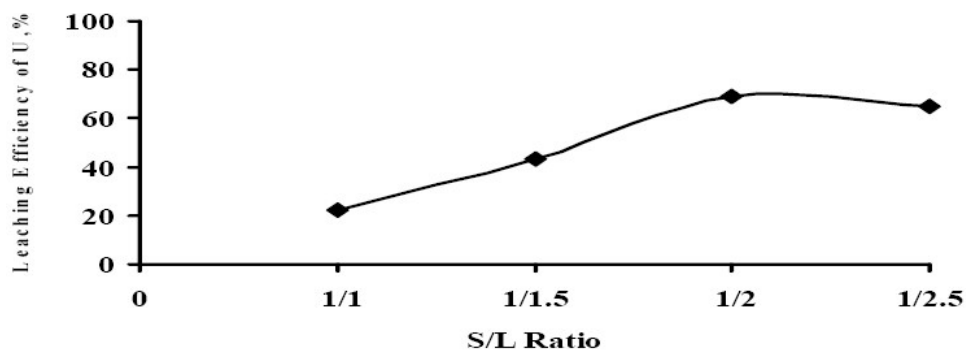

Figure 3 : Effect of S/L ratio upon leaching efficiency of U from El Sahu xenotime-bearing ferruginous sandstone ore material
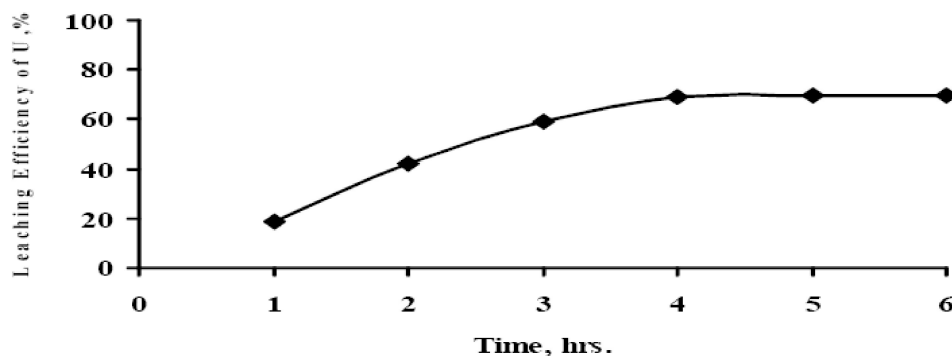

Figure 4 : Effect of agitation time upon leaching efficiency of U from El Sahu xenotime-bearing ferruginous sandstone ore material

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ing efficiency under the applied conditions.

iii) Effect of agitation time

To study the effect of agitation time upon the leaching efficiency of uranium, a set of leaching experiments has been performed at different time periods ranging from 1 to 6 hrs. The other leaching conditions were fixed at a Na_2CO_3 conc. of 90 g/l, 1/2 S/L ratio at room temperature (25°C) and using the ore ground to -200 mesh size. The corresponding leaching efficiencies have been plotted in Figure 4.

From the obtained results, it is clear that the leaching efficiency of U from the working ore increased from 19 to 69 % by increasing the agitation time from 1 to 4 hrs respectively. Further, increase in the leaching time at 5 & 6 hrs has not improved the leaching efficiency thereafter.

iv) Effect of leaching temperature

The effect of leaching temperature upon the leaching efficiency of uranium from the working ore was investigated at 50 and 75°C under the fixed experimental conditions of 90 g/l Na_2CO_3 conc., S/L ratio of 1/2, leaching time of 4 hrs and using the ore ground to -200 mesh size. The obtained data are illustrated in Figure 5 in comparison with that obtained at 25°C.

From the obtained results, it is clearly evident that by increasing the leaching temperature to 50 and 75

°C, the leaching efficiency of U has however decreased from 69 down 58 and 46 % respectively. This is most probably to increased reaction which would increase NaOH formation and which might have led to U re-precipitation.

v) Effect of $NaHCO_3$ addition

From the obtained moderate U leaching efficiencies when using Na_2CO_3 alone as a leachant, it was found necessary to add $NaHCO_3$ so as to neutralize the formed NaOH. Accordingly, a series of leaching experiments were performed in which sodium bicarbonate was mixed with the 90 g/l sodium carbonate in a weight ratio of $Na_2CO_3/NaHCO_3$ of 18/1, 9/1, 6/1 and 3/1. The fixed leaching conditions involved a S/L ratio of 1/2 at 25 °C for 4 hrs and using the ore ground to -200 mesh size. The corresponding leaching efficiencies have been plotted in Figure 6.

From the obtained results, it can be concluded that the leaching efficiency of uranium has increased by $NaHCO_3$ addition and that this increase is obtained with decreasing the weight ratio of $Na_2CO_3/NaHCO_3$. Thus, by decreasing the weight ratio of $Na_2CO_3/NaHCO_3$ concentration from 18/1 to 3/1, the corresponding leaching efficiencies have increased from 77 up to 97.2 % respectively. Therefore, it can be concluded that the weight ratio of $Na_2CO_3/NaHCO_3$ of 3/1 would be con-
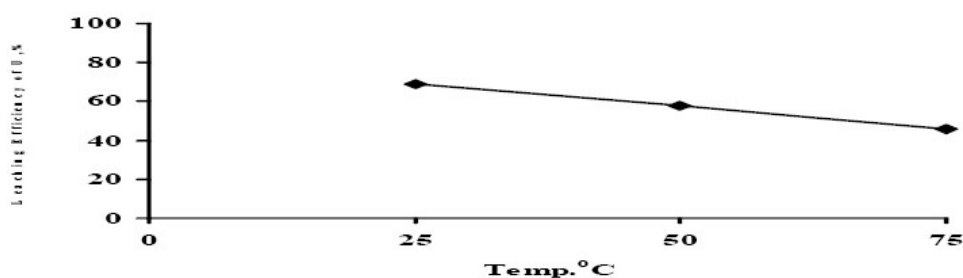

Figure 5 : Effect of leaching temperature upon leaching efficiency of U from El Sahu xenotime-bearing ferruginous sandstone ore material
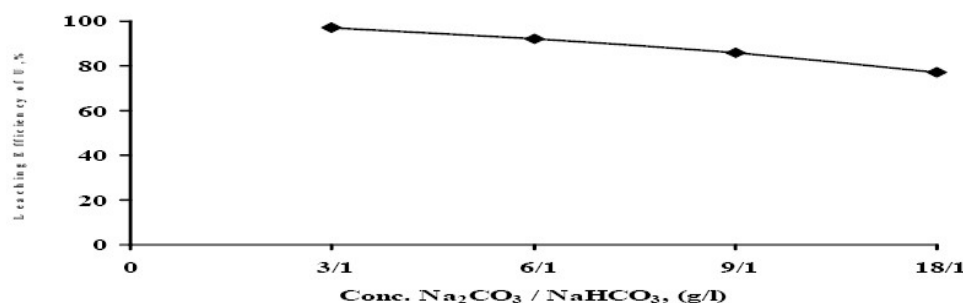

Figure 6 : Effect of $Na_2CO_3/NaHCO_3$ conc. upon leaching efficiency of U from El Sahu xenotime-bearing ferruginous sandstone ore material

sidered as an optimum weight ratio for about 97 % uranium leaching. This increase in U leaching efficiency is actually due to presence of $NaHCO_3$ which prevents the solution pH from rising by the formed NaOH to the point where diuranate would precipitate. Actually, this result of working at room temperature prove that uranium is loosely adsorbed upon the iron oxides and clay mineral and not involved in the xenotime mineral of the working ore material.

vi) Effect of ore grain size

The decreased grain size of the input ore material is actually more important in alkaline leaching than in acid leaching. This is due to the fact that the effective surface area should be increased to obtain better contact with the relatively weak alkaline leaching agent. Accordingly, it was found necessary to investigate the high leaching efficiency exceeding 97 % at grain sizes coarser than 200 mesh size. For this purpose, a set of leaching experiments has been performed using the previously studied optimum conditions, however using different ore samples ground to coarser mesh sizes beginning from "as received" to -150. The obtained data are illustrated in Figure 7 in comparison with obtained at -200 mesh size

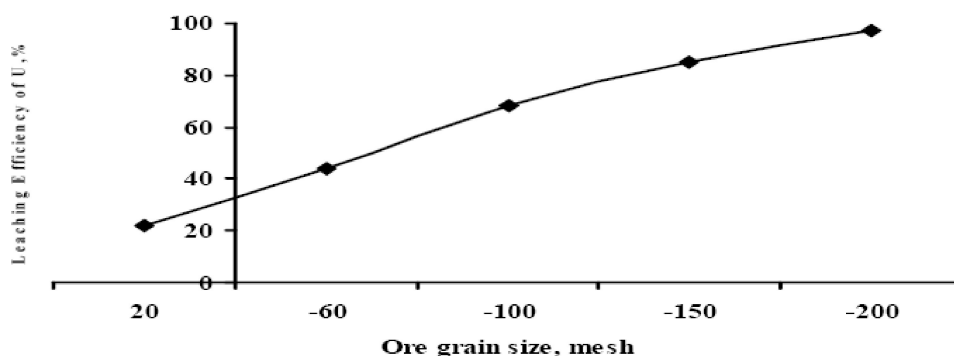From the obtained results, it is clearly evident that the leaching efficiency of uranium from the "as received" sample whose grain size exceeds 20 mesh, attain only 22 %. Complete grinding of the received ore samples from -60 to -150 mesh size, has increased the U leaching efficiency from 44 to 85 %; a matter which necessitates the grinding working ore to -200 mesh size to obtain U leaching efficiency exceeding 97 %. From the above studied alkaline leaching factors for U from El Sahu xenotime-bearing ferruginous sandstone ore material, it can be concluded that the optimum conditions for dissolving up to 97.2 % of the U content can be summarized as follows:

- Alkali concentration : 90 g/l Na_2CO_3 / 30 g/l $NaHCO_3$
- S/L ratio   : 1/2
- Time   : 4 hrs.
- Temperature   : room temperature
- Ore grain size   : -200 mesh
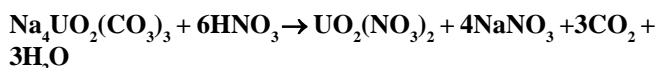
Uranium recovery

In the present work, it was decided to recover U from the prepared pregnant alkaline leach liquor of El Sahu xenotime-bearing ferruginous sandstone ore material by using two techniques: namely the direct precipitation technique and the prior application of anion-exchange resin technique using Amberlite IRA-400. For this purpose, an alkaline leach liquor was prepared by

Figure 7 : Effect of the ore grain size upon the leaching efficiency of U from El Sahu xenotime-bearing ferruginous sandstone ore material

TABLE 3 : Chemical composition of the prepared pregnant solution of U from El Sahu xenotime-bearing ferruginous sandstone ore material

Metal ion	Conc., g/l
U	0.230
CO_3^{2-}	48.40
HCO_3^-	19.80
pH	9.7

applying the previously studied optimum leaching conditions upon 1 Kg of the working ore. After filtration, the ore residue was thoroughly washed and the washings were added to the original filtrate making up to 3 liters leach liquor. The pH of the produced pregnant solution was found to attain 9.7 and assay 0.230 g/l U as shown in TABLE 3 while the CO_3^{2-} and HCO_3^- attain 48.4 and 19.8 g/l respectively.

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Direct precipitation of uranium

In the applied direct precipitation technique, it was found more convenient to obtain a uranium oxide product via preparation ammonium diuranate. Accordingly, the pH of the obtained alkaline pregnant liquor was decreased to 5.2 using nitric acid. This was followed by addition of ammonium hydroxide to the obtained uranyl nitrate solution till a pH value of 10-12. At this pH, a much more pure ammonium diuranate product was precipitated which was then calcined at 850 ^{o}C for 1 hr. The obtained uranium product has also been titrimetrically analyzed against ammonium metavanadate and was found to attain up to 96 %. The involved reactions can be represented as follows.

$$Na_4UO_2(CO_3)_3 + 6HNO_3 \rightarrow UO_2(NO_3)_2 + 4NaNO_3 + 3CO_2 + 3H_2O$$

$$2UO_2(NO_3)_2 + 6NH_4OH \rightarrow (NH_4)_2U_2O_7 + 4NH_4NO_3 + 3H_2O$$

Recovery of uranium via anion exchange resin

i) Uranium adsorption

Another 3 liters of the carbonate leach liquor prepared by leaching 1 Kg of the working ore material under the studied optimum leaching factors were subjected to a prior anion exchange resin recovery using Amberlite IRA-400. However, before U adsorption,

the pH of the prepared leach liquor was first adjusted at 9.0. The latter was then passed through a resin column containing 7.5 ml of wet settled Amberlite IRA-400 anion exchange resin (w.s.r) using a contact time of 5 min (flow rate of 0.6 ml/min.). The obtained effluent was collected every 150 ml for uranium analysis. The obtained results are plotted as an adsorption or loading curve in Figure 8. The solution throughput volume passing through the resin was continued until the effluent or the output uranium concentration was the same as that of the influent or the input feed. The adsorbed uranium content on the resin was then properly calculated and was found to attain 0.57 gm which is equivalent to 76 g U/L w.s.r. The latter is equivalent to about 84% of the theoretical capacity determined by El Hazek (1965) of 1.52 meq/ml w.s.r. (about 90 g U/L w.s.r.).

ii) Uranium elution

In the present work, the chloride elution system has been used and made with 1M sodium chloride solution acidified with 0.15N H_2SO_4. This eluant solution was passed through the saturated resin sample using a contact time of 6 min (flow rate of 0.5 ml/min) after washing the working resin column by distilled water. The obtained eluate solution was collected every 25 ml for
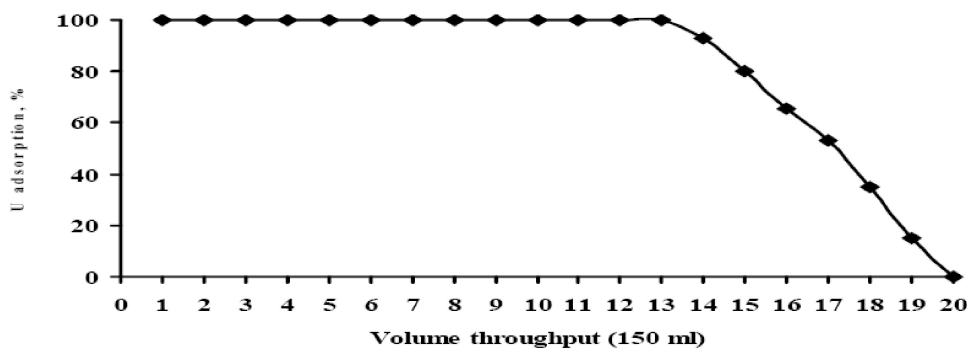

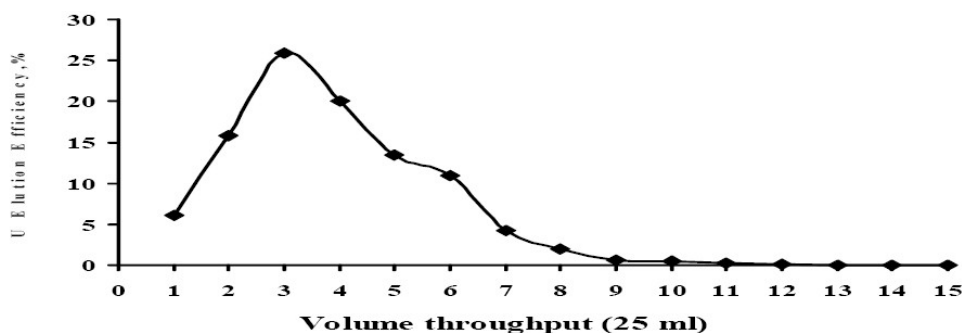**Figure 8 : Adsorption curve of uranium from sulfate leach liquor**

Figure 9 : Uranium elution curve from the saturated Amberlite IRA-400 resin column

uranium analysis. The obtained results are and plotted in Figure 9 as an elution curve.

From the obtained results of uranium elution, it is clearly evident that the eluted uranium content from the used column attained 0.49 g. This corresponds to an elution efficiency of about 86% of the adsorbed uranium content upon the used column (76 g U/L w.s.r.).

iii) Uranium precipitation

After collecting the obtained eluate samples, the pH of the obtained solution was adjusted to about 7.5 using 10% NaOH solution where uranium was precipitated as sodium di-uranate ($Na_2U_2O_7$). After filtration and calcination of the obtained product, it was subjected to EDAX analysis Figure 10 from which it is clearly evident that uranium is the main product assaying up to about 87 % besides only quite low levels of the associated impurities.

On the other hand, uranium in the obtained product was also titrimetrically analyzed against ammonium metavanadate and was found to assay about 88%.

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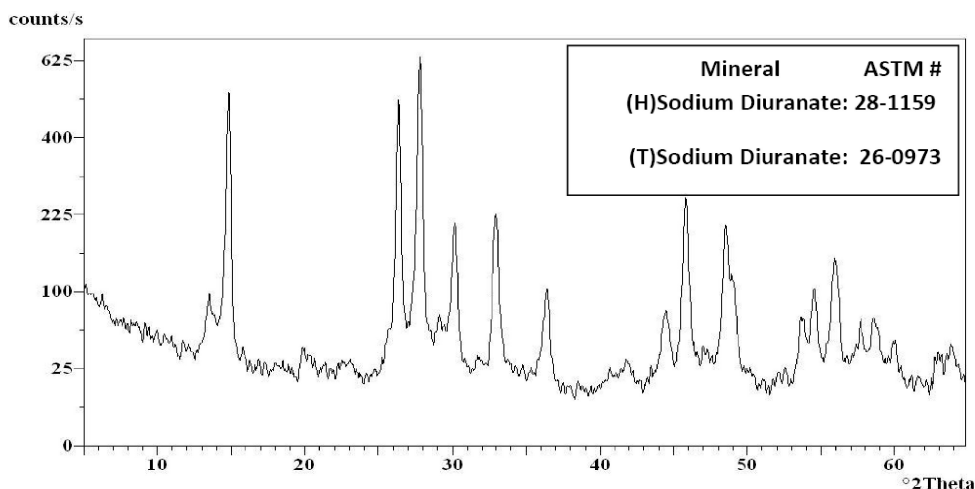

Figure 10 : XRD analysis of the obtained $Na_2U_2O_7$ product from El Sahu xenotime-bearing ferruginous sandstone ore material

CONCLUSION

A technological flowsheet Figure 11 for the selective recovery of uranium from Wadi El Sahu xenotime-bearing ferruginous sandstone ore material (710 ppm U) has been formulated. The latter involves alkali agitation leaching of the ore material and where the studied optimum conditions includes 90 g/l Na_2CO_3 concentration, 30 g/l $NaHCO_3$ concentration at a S/L ratio of 1/2 for 4 hrs agitation time at room temperature and using an ore grain size ground to -200 mesh. Under these conditions, a uranium leaching efficiency of 97.2 % has been obtained. From the obtained leach liquor, U was separated through two techniques; namely di-

rect precipitation and a prior application of anion exchange resin. In the former, the liquor was acidified using HNO_3 solution till a pH of 5.2 followed by direct precipitation using ammonium hydroxide. The precipitate was then calcined at 850^0C for 1 hr. to obtain on U_3O_8. In the second technique, U was selectively recovered from the obtained leach liquor using Amberlite IRA-400 and from the obtained elute, U was precipitated as sodium di-uranate ($Na_2U_2O_7.2H_2O$). The obtained precipitate was calcined at 850^0C for 1 hr. to obtain on $Na_2U_2O_7$. The two products were then analyzed by both EDAX and titrimetrically. The former indicated a U purity of 96 % and 87 % for the direct precipitation technique and the prior application of an-

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ion exchange resin respectively. On the other hand, the titrimetric technique indicated a U purity of about 96 % and 88 % for the product obtained by the direct pre-

cipitation technique and that the prior application of anion exchange resin respective
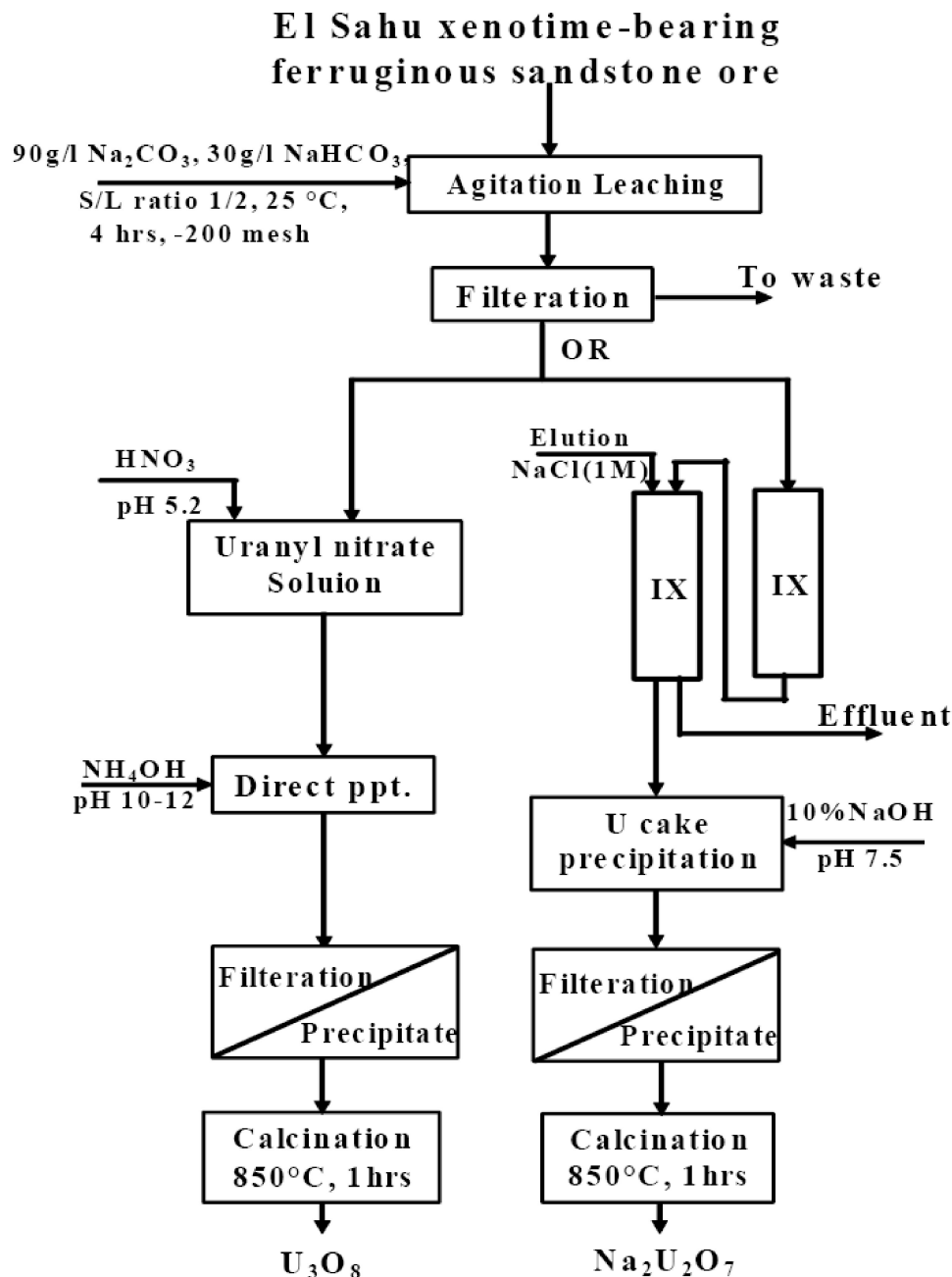
El Sahu xenotime-bearing ferruginous sandstone ore

90g/l Na_2CO_3, 30g/l $NaHCO_3$
S/L ratio 1/2, 25 °C,
4 hrs, -200 mesh

Agitation Leaching

Filteration → **To waste**

OR

HNO_3
pH 5.2

Elution
NaCl(1M)

Uranyl nitrate Soluion

IX   IX

Effluent

NH_4OH
pH 10-12

Direct ppt.

U cake precipitation   10%NaOH
pH 7.5

Filteration / Precipitate

Filteration / Precipitate

Calcination 850°C, 1hrs

Calcination 850°C, 1hrs

U_3O_8

$Na_2U_2O_7$

Figure 11 : Proposed technical flow sheet for selective of uranium from xenotime-bearing ferruginous sandstone

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