Res.J.Chem.Sci. *Research Journal of Chemical Sciences*
Vol. **1(4),** 55-66, July **(2011)** ISSN 2231-606X

Bioleaching Treatment of Abu Zeneima Uraniferous Gibbsite Ore Material for Recovering U, REEs, Al and Zn

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Available online at: www.isca.in
(Received 9th May 2011, revised 20th May 2011, accepted 6th June 2011)

Abstract

The chemical processing of the mineralized gibbsite ore material of Um Bogma formation occurring at Abu Zeneima area of Sinai has been studied for the recovery of its metal values .A technological sample assaying 26.43% Al_2O_3 , 0.43% Zn, 0.49% Rare earth (REEs) and 500ppm U has thus been subjected to several bioleaching experiments to avoid excessive acid consumption. In these experiments, the autotrophic bacteria Acidithiobacillus ferrooxidans was used and the relevant leaching conditions were optimized. From properly prepared pregnant sulfate leach liquor, the leached metal values were recovered in the form of marketable products.

Key Words: *Recovery, uranium, REEs, Abu zeneima gibbsite bioleaching*

Introduction

Exploration program of the Nuclear Materials Authority (NMA) is mainly concerned with the uranium and other nuclear materials as well as possible interesting associated metals. During these works, the potentiality of proper processing of these resources especially the low grade ores would be needed. Among the latter, the lower Carboniferous sedimentary sequence of Um Bogma formation located at Abu Zeneima area, Southwestern Sinai between longitudes 33º 20` to 33º 25` E and latitudes 29º 00` to 29º 05 N was found to be variably mineralized .The uraniferous gibbsite ore material of this sequence was chosen for the present work due to its added values of both REEs and Zn in relatively reasonable grades.

Several leaching studies have been performed upon comparable Abu Zeneima ore materials from different locations and involving different host rock types with different constituents and grades of the economic metal values. Thus, several works have studied the leaching and extraction efficiencies of Al, Zn and U and have proposed 2 flowsheets. [1-6]

Some studies have also succeeded to leach Al, Cu, Zn, Co, Ni and U beside several Mn minerals from a comparable ore materials using sulfuric acid.[7] The optimum leaching conditions were found to include 800 g/L acid with a solid/liquid ratio of 1/2 at 100 °C for 4 hrs and using an ore size of −60 mesh. Under these conditions, it was possible to achieve high leaching efficiencies with complete leaching of Al; namely 93.0% Cu, 58.6% Zn, 69.0% Co, 92.6% Ni and 84.4% U. Some studies have also studied the optimum conditions for leaching another occurrence of Abu Zeneima gibbsite ore material; viz, 30% H_2SO_4 in a solid/liquid ratio of 1/3 for 5 hrs at ambient temperature (25±5°C). Under these conditions, the realized dissolution efficiencies attained 97.6, 91.1 and 90.3% for Al, Zn and the REEs, respectively[8].

In these studies, sulfuric acid leaching has been applied and has proven that the mentioned metal values are quite amenable to acid leaching, however, at the expense of relatively high acid consumption. This is mainly due to the presence of relatively high carbonate content besides dissolution of gibbsite in these ore materials.

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Bio-hydrometallurgy, which exploits microbiological processes to recover heavy metal ions, is actually regarded as one of the most promising and revolutionary biotechnologies. The use of microbes to extract metals from their ores is based on the harnessing of natural microbial processes for commercial purposes whereby metal extractions would be done through leaching by acidophilic sulfur-oxidizing and iron-oxidizing bacteria. As a matter of fact, microbes have been intimately involved in both the deposition and solubilization of heavy metals in the earth's crust since ancient geological times**.** In these processes, acidophilic bacteria oxidize sulfide minerals to soluble products and new solid phases may also be formed. Soluble iron is central in these systems where Fe^{2+} is oxidized by microorganisms to Fe^{3+} which often acts as a chemical oxidant in the further acid leaching of sulfide minerals and is subsequently recycled to Fe^{+2}[9].

In this regard, it has to be mentioned that from the theoretical point of view, bioleaching is primarily achieved by two mechanisms that describe two procedures; namely a direct and an indirect leaching routes. In the former, *Acidothiobacillus ferrooxidans* becomes attached to the mineral particles and then the enzymes associated with the cell membrane would catalyze an oxidative attack on the crystal lattice of the metal sulfide as shown in the following equation 1

$$FeS_2+7/2O_2+H_2O \xrightarrow{\text{Bacteria}} FeSO_4+H_2SO_4 \quad \mathbf{1}$$

On the other hand, indirect leaching depends on the ability of various species of the acidophilic microorganism *Acidothiobacillus ferrooxidans* to generate a metabolic energy by oxidizing either ferrous or sulfur component in a manner to produce ferric sulfate according to the following equations 2 and 3

$$2FeSO_4+ H_2SO_4+1/2O_2 \xrightarrow{\text{Bacteria}} Fe_2(SO_4)_3+H_2O \quad 2$$

$$UO_2 + Fe_2 (SO_4)_3 \longrightarrow UO_2SO_4 + 2FeSO_4 \quad 3$$

The bioleaching process is indeed governed by the activity of the involved microorganisms and that maximum efficiency of metal solubilization can only be achieved when the bioleaching process conditions correspond to the optimum growth conditions of the bacteria[10]**.**

The present work aims to study the potentiality of columnar bioleaching and recovery of both Al and U as well as the associated REEs and Zn from the working gibbsite ore material of Abu Zeneima area. The purpose is to investigate the amenability of these metals value associated with the mineralized gibbsite to the bioleaching procedure in a manner to avoid excessive acid consumption due to the presence of a relatively high content of carbonate minerals. To realize these objectives, the different relevant factors affecting the columnar bioleaching of these metal values using *Acidithiobacillus ferrooxidans* strains have properly been studied. From the obtained leach liquor, the leached metal values have been subjected to convenient recovery procedures and the obtained data have been formulated in a workable flowsheet.

Materials and Methods

Ore Characterization: The working gibbsite ore sample was provided from variably mineralized lenses that occur within the shale beds of Um Bogma formation .The sample was collected from a layer of up to 2 m thickness and has been subjected to complete chemical analysis involving the major oxides besides the tenor of the economic metal values. Therefore, a representative portion of the collected technological sample was properly prepared by crushing, grinding to – 200 mesh size and quartering. The major oxides were analyzed using the rapid silicate analytical procedure[11]. This procedure involves the preparation of two main solutions; namely an alkaline one for SiO_2 and Al_2O_3 and an acid solution for the determination of most of the other oxides (CaO, MgO, total iron, Na_2O, K_2O, etc.) Special sample portions were used for the determination of the weight loss at various temperatures to estimate the loss of ignition.

Microbiological Studies: Preparation of the bacterial culture and nutrients: Mesophilic bacteria, iron–sulphur oxidizing bacteria have been isolated from a sulfur- containing waste and have then been properly cultivated for purification. The bacteria were grown in a mineral salt solution with the following composition: 6 gL^{-1} of $Fe_2 (SO_4)_3$, 0.2 $g{\cdot}L^{-1}$ of $(NH_4)_2SO_4$, 0.1 $g{\cdot}L^{-1}$ of KCl, 0.1$gL^{-1}$of K_2HPO_4, and 0.4 gL^{-1} of $MgSO_4{\cdot}7H_2O$.The medium was sterilized by filtration through a 0.22 µm filter membrane. The cultures *of Acidithiobacillus ferrooxidans* were incubated in 250 ml Erlenmeyer flasks containing 100 ml of the medium and 3% (volume fraction) inoculum on a rotary shaker at 170 rpm/min at 30^{o}C. The initial pH of the cultures was adjusted to 2.0 using 0.5 mol/l H_2SO_4. The stock and pre-inoculum cultures were maintained in the same medium under similar conditions. The cultures that were used had been subcultured through several transfers in the concentrated medium in order to adapt the bacteria to the experimental conditions. The stock cultures were subcultured at two-week intervals. The cell population in this inoculum has been determined by direct counting using a Petroff–Hausser chamber and was typically found in the range of (8-10) x10^8 /ml.

Columnar Bioleaching Procedure: In the present bioleaching study, the columnar technique has been used by packing about one kg ore portions (-60 mesh size) in proper columns measuring 120 cm high, with an internal diameter of 5 cm Each working sample portion was first wetted with 5 ml concentrated sulfuric acid before being loaded in the column. According to the procedures adopted by some considered a 500 ml volume of the proper medium was then added to the tested culture and has been allowed to circulate for a period of 48 hours by proper pumping at a flow rate of 2 ml per minute before the zero time sample was taken. Afterwards, periodical samples were continuously taken for 35 cycle periods[12-13]. The samples were analyzed every five cycles for the metals content to calculate the bioleaching rate. The leach solution was passed through the ore sample by gravity and recirculated through a side loop with a peristaltic pump. Several experiments have actually been carried out to study the relevant factors using the same procedure to determine the optimum condition for columnar bioleaching.

Recovery procedures: The determined optimum bioleaching factors have indeed been applied for the preparation of a sulfate pregnant leach liquor u, Al, Zn and REEs of Abu Zeneima gibbsite ore. However, it was found necessary before preparing marketable products of the leached metal values to properly subject their leach liquor to iron separation which is the most deleterious associated impurity. This has actually been achieved by increasing the pH of the pregnant liquor to 2.7 followed by filtration of the precipitated iron hydroxide and which represented about 87% iron separation. The pH of the filtrate was then re-adjusted to allow it to pass through the anion exchanger resin Amberlite IRA-400 for U adsorption while the effluent was subjected to oxalate precipitation of the REEs at pH value of 1 using 10% of oxalic acid.

The oxalate filtrate was then subjected to hydrolytic precipitation of Zn and Al using 10%. NaOH solution by first adjusting its pH to 3-3.5 for zinc precipitation.The pH of the obtained filtrate was then adjusted to 5.3 by 10% NaOH solution for the precipitation of Al

Analytical Procedures: The content of the processed metal values other than Al whether in the original sample or in the different stream solutions obtained during leaching and recovery procedures (U, Zn and REEs) were determined by proper techniques. Thus the REEs were spectropmeterically determined by the chromogenic reagent Arsenazo-III while uranium analysis was performed by an oxidimetric titration using ammonium metavanadate[14-15]. On the other hand Zn was analyzed using atomic absorption spectrophotometry (AAS) model Unicam 969, England**.** In the

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meantime, Al in these solutions has been analyzed using the above mentioned procedure[11]

Finally, the four obtained metal concentrate products have been analyzed using the environmental scanning electron microscope (ESEM)-energy dispersive X-ray analyzer EDX (model Philips XL300).

Results and Discussion

Characterization of Abu Zeneima gibbsite ore: As previously mentioned, the working technological sample was provided from Abu Zeneima gibbsite ore lenses found in the shale beds. Results of the complet chemical analysis of the working sample are shown in able 1. From the latter, it is clearly evident that SiO_2 is relatively low in the rock where its assay is less than 12% while Al_2O_3 attaining 26.43% reflects the relatively high attaining gibbsite mineral content. In the meantime, presence of about 13% Fe_2O_3 and about 7% MnO reflects the relatively abundant Mn mineralization in southwestern Sinai. On the other hand, the gibbsite ore is also characterized by a relatively high CaO and MgO contents reaching about 7 and 4 % respectively.

In a trial to calculate the possible mineral composition, it was found that gibbsite($Al_2O_3.3H_2O$) attains up to about 40% while the two carbonate minerals dolomite and calcite attain 18.4 and 2.5% respectively. On the other hand ,analysis of the interesting metal values in the working Abu Zeneima technological sample has revealed that besides 500ppm U, the REEs were found to assay up to 4900 ppm and Zn up to 3400ppm. Accordingly, in the following bioleaching studies, the leaching potentiality of Al, REEs, Zn and U would be investigated.

Columnar bioleaching results: Due to the fact that high grade ore deposits are getting rapidly consumed and depleted, it has thus become greatly necessary to recover mineral resources from their low-grade ore deposits. However, an appropriate economic technology is still unavailable for the proper recovery of the metal values from such low-grade deposits. Among the latter, microorganisms or bioleaching processes can be regarded as one of these encouraging procedures to do the job. Therefore, to investigate the applicability of bioleaching to the working gibbsite ore material, several series of experimental have been performed using proper solutions to optimize the different concerned factors. However, before undertaking the systematic study, it was found interesting to endeavour the feasibility of the working bacteria strain; namely *Acidithiobacillus ferrooxidans* in leaching the working metal values.

Two bioleaching experiments have thus been performed upon the leaching efficiencies upon the REEs, Al, U and Zn from the working ore material in the absence and presence of *Acidithiobacillus ferrooxidans* with cell population in the range of (8-10)x10^8/ml. The other leaching conditions were fixed at -60 mesh size ore and at room temperature. From the obtained leaching efficiencies, it was found that presence of *Acidithiobacillus ferrooxidans* is quite essential for leaching the working metal values from the mineralized gibbsite ore. The leaching efficiency of the REEs, U, Zn and Al have only been 4.89, 7.69, 3.33 and 5.22% respectively, while in presence of the former, the highest obtained leaching efficiencies of the REEs, U, Zn, and Al have attained 55.11, 44.91, 30.67 and 17.69% respectively. These results are conformable with published work who has indicated that the *Acidithiobacillus ferrooxidans* strain is the most important bacteria used in commercial microbial leaching of uranium from its ores[16] .However, due to the fact that the activity of bacteria is affected by various physical, chemical and biological factors, it is therefore crucial to understand the pragmatic operational conditions for optimum growth and a activity of the microorganisms involved in bioleaching process.

Effect of the incubation period: The effect of the incubation period upon bioleaching efficiency of the working interesting elements was studied in the range of time from 5 to 35 recycle while fixing the other factors at -60 mesh size ore finesses at room temperature using the autotrophic bacteria *Acidithiobacillus ferrooxidans* with cell population in the range of (8-10)x10^8/ml. The obtained leaching efficiencies plotted in figure 1 reveal a gradual increase with increasing the number of cycles till 30 cycles. Extending the incubation period to 35 cycles did not improve the obtained efficiencies at 30 cycles. These results indicate that both the REEs and U are relatively more easily leached than Zn and Al .Thus at cycle 30 and a measured pH of 2 and an Eh 350 mV the leaching efficiency of the REEs and U attained 55.13 and 44.91% respectively while for Zn and Al , it was only 30.67and 17.69% respectively. In this regard, it has to be mentioned that at cycle number 30 a relatively high potential value (Eh) of 350 mV was sufficient to transform the insoluble U (IV) form into the soluble U (VI) form .At the same time, the pH has progressively decreased with Eh increasing where it reached 2 after 30 cycles figure2. The obtained data are actually in agreement with comparable results obtained by published data who have found that the best uranium extraction was achieved at pH 2[17]

However, the high carbonate content of ore would increase the pH values in the leach suspensions; in a manner that sulfuric acid should be continually added to adjust the pH to about 3 to provide better conditions for growth of *Acidithiobacillus* [18]

Effect of sulfur addition: From the obtained bioleaching results of the working metal values and which reflect in-situ production of H_2SO_4 acid, it was thought that addition of sulfur would improve these results through increasing acid production by *Acidithiobacillus ferrooxidans.* Application of the elemental sulfur is due to the fact that it is less expensive than other substrates[19]. The effect of S /ore amount ratio upon REEs, Al, U and Zn dissolution was thus studied over a range from 0.1% to 0.5%. The other bioleaching conditions were fixed at -60 mesh size for the ore material, at room temperature for 30 cycles and using *Acidithiobacillus ferrooxidans* with cell population in the range of (8-10)x10^8 /ml. From the obtained leaching efficiencies plotted in figure 3, it is clear that increasing the amount of sulfur addition results in increasing the leaching efficiencies of the valuable metals. Thus, the obtained results show that when adding 0.5% S element, the highest leaching efficiencies were obtained; namely the REEs (65.58 %), U (53.99%), Zn (47.91%) and Al (20.36%). Comparing these results with those obtained in the absence of S, it was found that the dissolution efficiencies have increased from 55.11 to 65.58% for the REEs; from 44.91 to 53.99% for U; from 30.67 to 47.91% for Zn and from 17.69 to 20.36% for Al. The corresponding generated acid must have dissolved more iron which would in turn spontaneously dissolve more metal amounts. These results are actually in agreement with those of published data[20-21]. The former work has recorded that both elemental sulfur and sulfur slag contents have been used as external energy source for *Acidithiobacillus ferrooxidans*. The latter work has also indicated that the highest yield of uranium extraction of 59.2 % has been obtained with oxidizing sulfur bacteria from a miniralized granite ore after 21 days. However, if excess sulfur is added than required for metal solubilization, the residual sulfur will cause re-acidification of the treated sediments or soils during land application[22].

Effect of ore sterilization: To detect the effect of prior ore sterilization upon the leaching efficiencies of the different working metals, two columnar bioleaching experiments have been performed using a sterilized ore in one of them. In both experiments, 1 kg ore sample weight was used (-60 mesh size) at room temperature for 30 cycles and using *Acidithiobacillus ferrooxidans* with cell population in the range of (8-10)x10^8/ml together with 0.5% sulfur . The obtained data have evidently indicated that non sterilization of the ore increases the leaching efficiency with respect to that previously sterilized. Thus, the leaching efficiencies of the REEs, U, Zn and Al have increased to 67.58 %, 54.99%, 49.91% and 22.36 % respectively as compared to 65.78 %, 53.45%, 47.61 %and 20.36 %. These results are in line with those obtained by published data who recorded that uranium extraction was higher under the inoculated condition than under the uninoculated and sterilized condition[23].

Summing up, it can be concluded that the optimmum conditions for columnar bioleaching of the REEs, U, Zn and Al from the working mineralized gibbsite sample would involve the following: an ore ground to -60 mesh size and adding S to the extent of 0.5 % of the input ore amount which was wetted with 5ml conc. H_2SO_4/Kg using *Acidithiobacillus ferrooxidans* with cell population in the range of (8-10) x10^8 /ml and using 500 ml /1 kg ore sample for 30 cycles at a flow rate of 120 ml/hr at room temperature.

Finally, it has to be mentioned that the obtained bioleaching efficiencies of the studied metal values could indeed be improved by increasing S addition and probably the cycle number in a manner to increase acid production. A part from carbonate minerals present (about 21%) the latter in quite important due to the presence of about 40% gibbsite which requires 800g sulfuric acid for 1 kg ore.

Recovery procedures of the bioleached metal values: To study possible recovery procedures of the studied bioleached metal values, a proper-leach liquor thereof at pH 2 was prepared using the above mentioned optimum bioleaching factors. Chemical analysis of this liquor in g/l was found to attain 0.50 U, 3.39 Zn, 6.60 REEs and 61.60 Al

To ensure obtaining highly pure U, REEs, Zn and Al concentrates from the prepared leach liquor and apart from U , it was found advantageous to use the precipitation technique since the working liquor would almost be devoid of interfering metallic components after iron separation at pH2.7.

Ion exchange recovery of uranium: Uranium could indeed be seprated using the Amberlite IRA 400 anion exchanger where the competing anions would mainly include SO_4^{-2} and HSO_4^- which would excessively be adsorbed at pH values lower than 1.8 and therefore the pH of the working leach liquor was readjusted at this value after iron precipitation[24,25].
A resin sample of Amberlite I.R.A 400 measuring 2.7 ml wet settled resin (w s r) was packed over a glass wool plug in a Pyrex glass column of (0.5 cm radius). The prepared 500 ml sulfate leach liquor was then subjected to adsorption by passing through the prepared resin bed allowing contact time of 3.3 min i.e. flow rate of about 0.33ml / min. The effluent was collected every 25 ml and analyzed for uranium and the obtained results are shown in table 2.

Under the working conditions, it was found that the obtained uranium saturation level amounted to 76.48 g/l wsr, while represents about 83 % of the theoretical capacity of the working resin. Before uranium elution, the resin column was first washed with distilled water to displace of the pregnant solution. This was followed by passing the eluant solution composed of 1N NaCl acidified to 0.1M sulfuric acid using a contact time of 1.6 /min. and collecting the obtained eluate every 10 ml for uranium analysis. From the obtained elution results tabulated in table 3 it was found that the total eluted uranum amount reached has 193mg indicating an elution efficiency of about 93 %.

Uranium from the collected eluate was precipitated at a pH of about 5.5 using 40 % NH_4OH solution in the form of ammonium diuranate. However the latter was found to be greatly contaminated with some impurities and for this reason it was exposed to alkali leaching using mixed solution of 15% a Na_2CO_3 and 5% $NaHCO_3$in a S/l ratio of ¼ for 15 minute at 80C° where uranium would be selectively leached equation 4. The obtained uranyl concentrate filtrate was adjusted to a pH value of about 5.5 using 1molar H_2SO_4 solution and the resultant precipitated was calcined at 800 C° to U_3O_8 product . The latter was then analyzed by the electron microscope ESEM-EDX analysis and the obtained results indicate that U assay has increased up to about 91% figure 4- a.

$$UO_3+3Na_2CO_3+H_2O \longrightarrow Na_4UO_2(CO_3)_3 + 2NaOH \quad (4)$$

Successive precipitation recovery of REEs, Zn and Al: The uranium effluent sulfate solution containing the bioleached values from Abu Zeneima gibbsite; namely REEs, Zn and Al were then direct to their direct precipitation. Thus, the REEs were first precipitated using 30% oxalic acid at pH 1. The obtained REEs oxalate precipitate was then calcined at 800°C before being analyzed by ESEM-EDEX analysis the obtained results are shown in figure 4-b from the latter its clearly evident that the total REEs concentrate includs assays atotal about 83 % of La,Ce and Nd while Pr and Sm assay about 3 to 4% beside Y attaining a bout 4%.

The filtrate after oxalate precipitation of the REEs was then subjected to alkali precipitation using a 20% solution of NaOH at a pH value of 3-3.5. The precipitated $Zn(OH)_2$ was then properly washed, dried and calcined at 800°C to obtain pure ZnO. ESEM-EDEX analysis of the latter indicated a Zn assay of about 93% figure 4-c.

Finally the Al remaining in the bioleach liquor was precipitated as Al $(OH)_3$ using a 10% NaOH solution at a pH value not exceeding 5.3. The precipitate was then filtrating, washing, drying and calcination at 800°C from the. ESEM-EDEX analysis of the latter was found that the Al assays 65.03 % figure 4-d.

Conclusion

Proper bioleaching processing has been achieved for a carbonate rich mineralized gibbsite ore material from at Abu Zeneima area, sw Sinai was found necessary to avoid excessive acid consumption by the classical leaching methods. The metal values of this ore material included 0.34% Zn,0.49% REEs and 500ppm U beside 26.43% Al_2O_3 In the bioleaching process, the columnar techenique was applied upon non-sterilized material including 5% use *Acidithiobacillus ferrooxidans bacteria and circulating* the bioleach liquor for 30 cycles. Under these conditions, the obtained leaching efficiencies amounted to 67.58, 54.99, 49.91 and 22.36% for the REEs, uranium, zinc and aluminum respectively. Improving these values would require increasing the bacterial cell number. The obtained data have been formulated in a prepared flowsheet figure 5.

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Table-1: Chemical composition of the working Abu Zeneima mineralized gibbsite ore material

Oxides	Wt.%	Oxides	Wt.%
SiO_2	11.77	CaO	7.03
TiO_2	0.87	Na_2O	2.04
MnO	6.90	K_2O	1.87
Al_2O_3	26.43	P_2O_5	0.12
Fe_2O_3	13.33	L.O.I.*	23.48
MgO	3.98	Total	97.82

L.O.I.* loss on agnation

Table-2: Analytical results of uranium in the bio-leach effluent sulfate liquor of Abu Zeneima mineralized gibbsite ore material using Amberlite I.R.A 400 resin

Effluent sample No.(25 ml)	Effluent uranium assay,ppm	Uranium adsorption efficiency %	Adsorped uranium ,mg
1	Nil	100	12.50
2	Nil	100	12.50
3	Nil	100	12.50
4	Nil	100	12.50
5	Nil	100	12.50
6	Nil	100	12.50
7	Nil	100	12.50
8	Nil	100	12.50
9	Nil	100	12.50
10	Nil	100	12.50
11	Nil	100	12.50
12	Nil	100	12.50
13	Nil	100	12.50
14	Nil	100	12.50
15	Nil	100	12.50
16	119	76.2	9.53
17	257	48.6	6.08
18	390	22.17	2.75
19	448	10.4	1.3
20	495	1	0.125
		Sum	207.285

Table-3: Analytical results of uranium in the eluate samples from the working Amberlite I.R.A 400 saturated resin column

Eluate sample No.(10 ml)	Uranium assay g/l
1	1.59
2	3.87
3	7.48
4	3.44
5	1.8
6	1.1

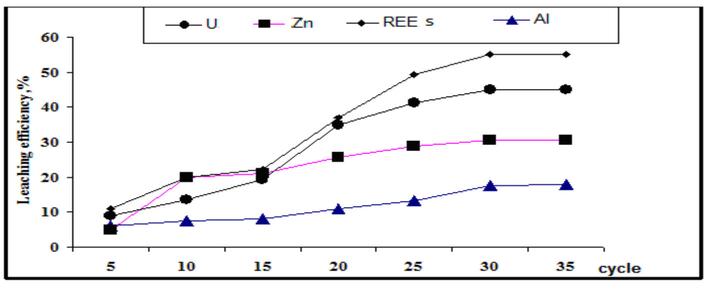

Figure-1: Effect of incubation period upon the columnar bioleaching efficiencies of REEs, U, Zn and Al of Abu Zeneima mineralized gibbsite ore material

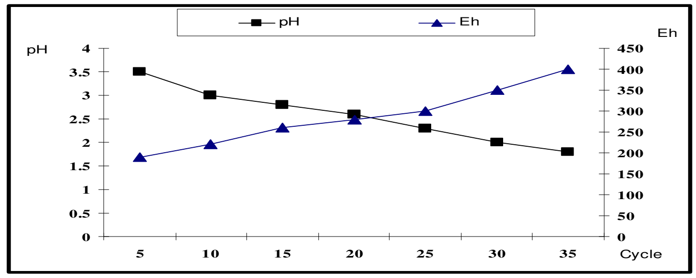

Figure-2: Effect of pH upon Eh during the incubation period of 35 cycles in columnar bioleaching of Abu Zeneima mineralized gibbsite ore material

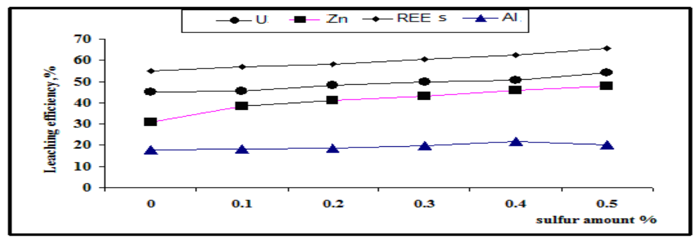

Figure-3: Effect of sulfur addition upon the columnar bio- leaching efficiencies of REEs, U, Zn and Al of Abu Zeneima mineralized gibbsite ore material

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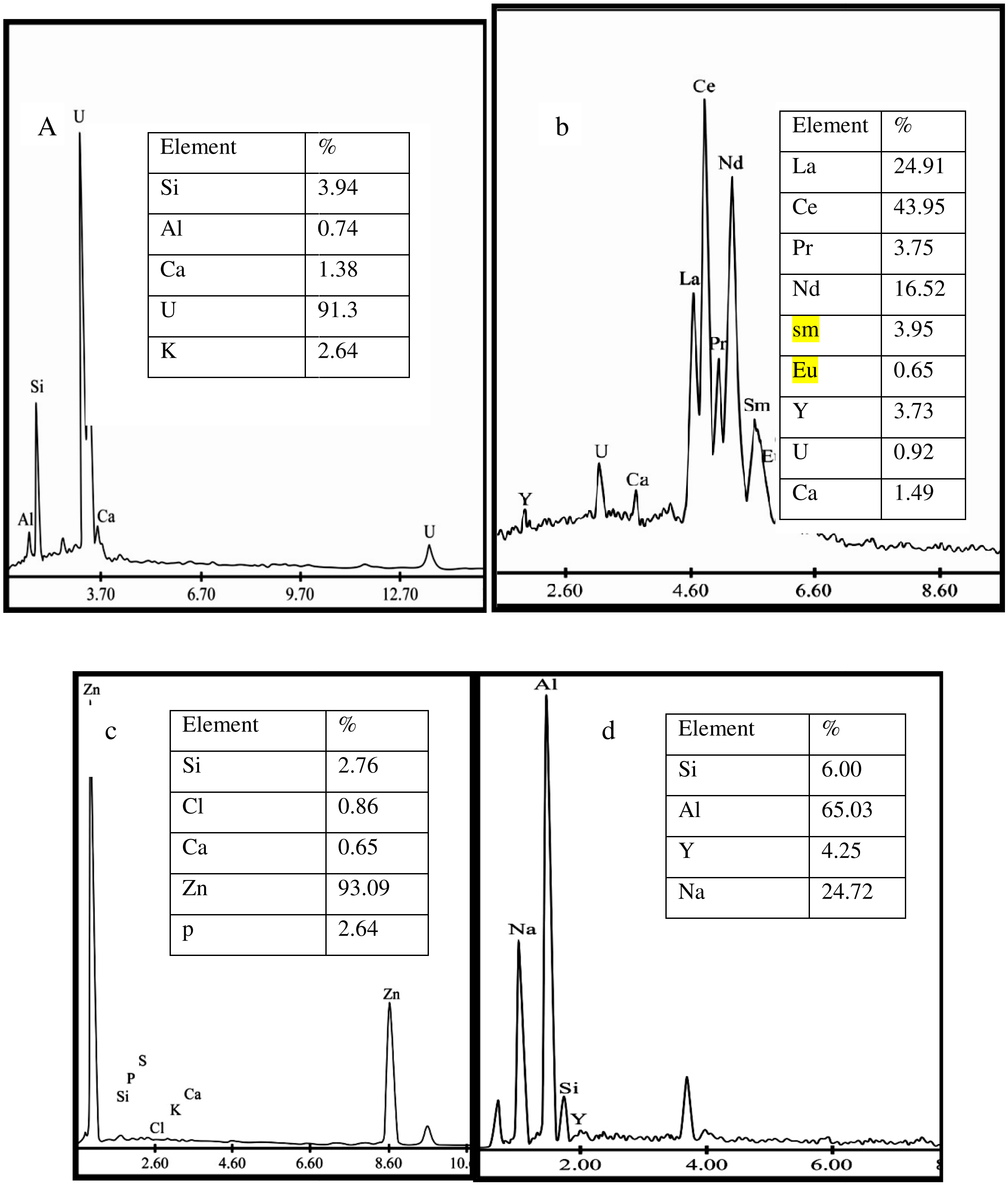

Figure-4: ESEM-EDX analysis of the prepared calcined products of U(a) ,REEs(b),Zn(c), and Al (d)after precipitation at pH 3-3.5 and calcinations at 800C°

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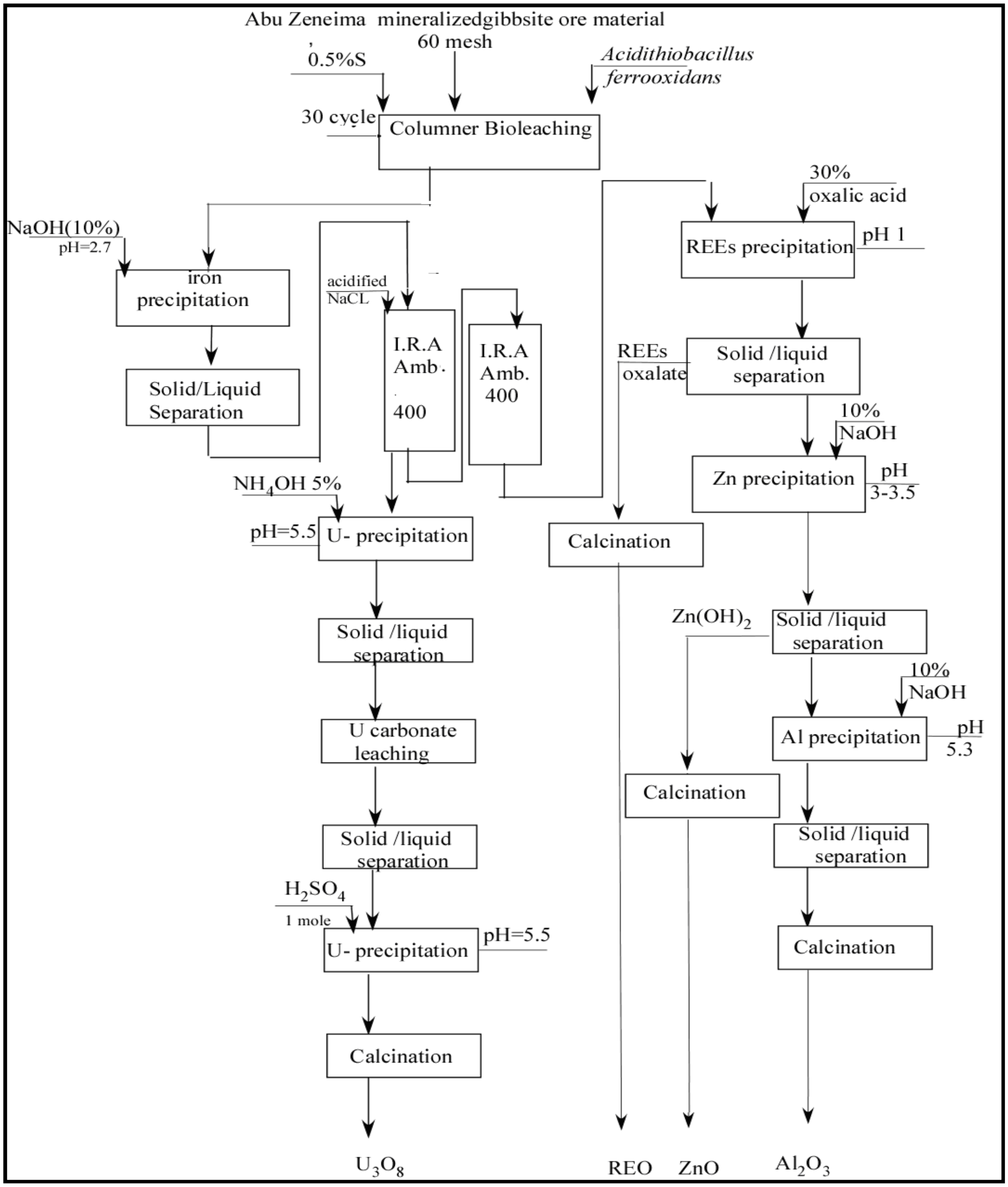

Figure-5: Proposed flowsheet for the recovery of U, REEs , Zn and Al from the bioleach liquor Abu-Zeneima mineralized gibbsite or