Original Research Article

Capability of Uranium Heap Leaching from Gattar and El Missikat Area, Eastern Desert, Egypt: A Kinetic Approach

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Detailed studies of uranium heap leaching from different uranium mineralization resources situated in Eastern Desert of Egypt were investigated using sulfuric acid via batch experiments. Bench scale leaching tests using small column were also investigated after optimum conditions were obtained. The obtained data indicated that leaching of GII mineralization attained about 78.3% using 34 kg/ton at 44 days leaching time. On the other hand, leaching efficiency of uranium from El Missikat mineralization was about 86.6% which is higher than GII mineralization using 28kg/ton at a 40 days leaching time. Kinetics reaction models of column tests were investigated to improved understanding of the chemical reaction mechanism involved in the dissolution of this refractory mineral that influence the leaching process. Based on the leaching results of the two mineralized occurrences, the rate of the uranium dissolution is controlled by both the chemical reaction and the diffusion reaction. However, the diffusion reaction control was more predominant than the chemical reaction.

Keywords: El Missikat, Gattar, Heap leaching, Column test, Kinetic reaction models.

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INTRODUCTION

Heap leaching is an industrial mining process used to extract precious metals, copper, uranium, and other compounds from its low grade bearing ores or mineralization's using a series of chemical reactions. In uranium heap leach mining, from its mineralization places on heap pad, followed by adds the chemicals reagents via drip irrigation systems to the ore (Lupo, 2009).

The main heap leach mining works suggested for large volumes of low grade ores as, it reduce the coast of metallurgical treatment of the used ore. The significantly reduced processing costs are offset by the reduced yield of usually approximately 60-70%. Also the main advantage of the heap process is the amount of overall environmental impact caused by heap leaching which is often lower than more traditional techniques (Bouffard and Dixon, 2001).

Progress of heap leaching studies by using column leaching methods have the advantages of allowing observers to study

longer term chemical interactions between solid samples and leachates, to note changes in the permeability of solid samples with time, and to evaluate how chemical reactions may change once more soluble compounds are flushed out of the solids (Ding et al., 2012).

In Egypt, several promising uranium occurrences have been discovered in the Eastern Desert such as, Gable Gattar , El Missikat, Abu Rushed and El-Sela areas. Gabal Gattar are allies in the northern part of the Eastern Desert at the intersection of coordinate 27°06'N and 33°16'E at a distance of 95Km from Hurgada City, at the Red Sea Coast. The mineralization mainly associated with granite as in G-II occurrence and with Hammamate sedimentary rocks as in case of G-V occurrence. According to Mahmoud (2000), petrographical examination of GII fresh granite has revealed that it is mainly composed of orthoclase perthite (with subordinate microcline perthite), quartz and plagioclase beside minor amounts of biotite and muscovite. On the other hand, the accessory minerals are represented by zircon, fluorite, apatite and sphene (Mahmoud, 2000).

El Missikat uranium prospect area lies at about 3 km, midway between Safaga, on the red Sea coast and Qena in the Nile Valley. It is roughly bound by longitudes 33°15` - 33°28` E and latitudes 26°24` - 26°30` N, where the mineralogical studies revealed the presence of uranium minerals such as uranophane, uraninite, soddyite and renadite (Amer et al., 2005). The main accessory minerals are sulfides, magnetite, zircon, apatite, fluorite, titanite, monazite, xenotime, uranothorite, rutile and uraninite. Hematite, epidote, muscovite and chlorite are present as secondary minerals (Attawiya, 1984; Ibrahim, 2002).

Several works have been achieved to leach U and associated valuble elements from G-Gattar prospect. Leaching of uranium and molybdenum from G-Gattar mineralization using acid and alkaline agitation leaching was studied. Acid leaching has indicated that complete leaching of U/MO by using 50g/L H_2SO_4 and solid/liquid ratio of 1/2 at room temperature for an agitation time of 12 hr. About 95.1% of uranium leaching efficiency was obtained at 60°C for 8 hr by using 50g/L Na_2CO_3 or $NaHCO_3$ in case of alkaline leaching (Dabbour, 1989; Mahdy et al., 1990; Kamal, 1995).

Uranium percolation leaching from both Gattar-II and Gattar-V mineralized samples were also studied. From the obtained results, the particle size has a significant impact on the leaching efficiency. With regards to the GII mineralization, the leaching efficiency of -10 mm sample is 76.9%, but the leaching efficiency of -40 mm sample is 47.4% (Mahmoud et al., 2001).

The leaching studies achieved on El Missikat attained the efficiency reached to 91% after 8 hr of agitation (Mohamed, 1995). In the same path, the contained REE leaching is studied during uranium recovery, which achieved leaching efficiency of about 95% (Mousa et al., 2014; Amin, et al., 2017). Agitation and column percolation leaching techniques applied upon the uranium rich mineralization (El Missikat) showed that these techniques succeeded in providing considerable results (Nagar et al., 2020).

The main objective of the present work is to investigate the kinetics of refractory gotten from Gattar and El Missikat and uranium mineralization dissolution process using sulfuric acid in order to improve understanding of the chemical reaction mechanism that is involved in the dissolution of this refractory mineral that influence the leaching process. The second goal of this work is to further consider the flexibility of heap leaching application via studying the optimum conditions required for uranium dissolution from the two previous uranium occurrences. Kinetics reaction models of column tests have been investigated to optimize the column leaching behavior.

EXPERIMENTATION

Characteristics of the Study Mineralized Sample
Two representative composite samples were used to carry out this study one from Gabal Gattar and the other from El Missikat occurrences. Chemical analysis was carried out by using inductively coupled plasma-atomic emission spectroscopy (ICP-AES) for analyzing major elements and compounds. The chemical composition for both major and trace elements are shown in Table 1.

From Table 1 it is obvious that, the two analyzed samples are nearly similar in major oxides, except that the El Missikat show higher in silica content relative to Gattar sample and also have more economic elements such as REEs, Ba, Cu and Sr , relative to GII.

All acid leaching testes were carried out using distilled water and concentrated sulfuric acid H_2SO_4 (Merk) as the lixivant solution and A.R grade of other chemical reagents. The hydrogen ion concentration (pH) of the different solutions was measured accurately using the pH- meter model (HAANA pH-mV-temp).

Uranium Leaching

Grain size analysis
Grain size analysis was performed upon 1.0 Kg as representative sample from the studied occurrences where the two samples were subjected to both crushing and sieving along with + 1.25, -1.25 to +0.5, -0.5 to +0.25, and -0.25 mm size fractions. After that, all fractions of grain size were analyzed for uranium.

Batch test conditions (agitation leaching)
To study and determine the optimizing factors affecting the uranium dissolution using acid agitation, a series of agitation leaching experiments were performed after selecting the appropriate sample weight (g), ground to appropriate size

Table 1. Chemical composition of GII and El Missikat representative sample.

Oxide	GII %	El Missikat %	Trace Elements	GII ppm	El Messikat ppm
SiO_2	75.30	87.97	Mo	49	4
TiO_2	0.28	0.11	Co	5	5
Al_2O_3	10.30	3.4	Zn	220	400
Fe_2O_3	2.10	4.4	Ba	71	200
FeO	0.53	0.58	U	1300	1850
MnO	0.02	0.1	REEs$\sum$	85	130
MgO	0.50	1.16	Zr	30	200
CaO	1.69	0.55	Cu	16	100
Na_2O	3.50	0.078	Th	29	20.5
K_2O	3.40	0.068	Nb	88	87.5
P_2O_5	0.50	0.75	Sr	<2	201
L.O.I	1.60	1.7	Cr	4	Nil
Total	**99.72**	**100.7**	Ni	5	80
			Pb	87	417

(µm) and was mixed well with a suitable volume of different sulfuric acid concentrations. The studied factors are; grain size, uranium distribution, agitation time, and suitable sulphuric acid concentration.

$$\% \text{ leacheability} = \frac{\text{U concn in sample } - \text{ U concn in residue}}{\text{U concn in sample}} \, x \, 100$$

Column test application
Leaching experiments were conducted using PVC columns (5 cm ×100 cm high). To avoid the "side wall effect", the inner wall was polished with sandpaper in advance to increase the roughness. The top of the leaching column was opened; the bottom was reserved for the outlet of the duct to collect the leachate and was covered with 5cm layer of the 5-mm-thick quartz sand particles.

Uranium control analysis
Uranium was analyzed in the corresponding low concentration of aqueous phases using ArsenazoIII reagent under different conditions (Marczenko, 1976). In high concentration (≥ 10ppm) uranium was determined in the pregnant solution and the crude uranium concentrate using the oxidimetric titration procedure with a standard solution of NH_4VO_3 till the appearance of a purplish red color represents the end point (Davies and Gray, 1964).

RESULTS AND DISCUSSION

Chemical composition of GII and El Missikat uranium occurrence
In GII and El Missikat, the ferric ion percent is relativity high about 2.1 and 4.4% respectively, and therefore controlled leaching conditions must be applied to minimize iron dissolution in order not to interfere with uranium during ion exchange recovery. In such situation, sulfuric acid becomes an excellent reagent used to dissolve uranium. Since most uranium minerals can be leached only when they have been oxidized, oxidizing conditions are maintained by ferric ions, which are generated by the oxidation of the ferrous ions present in solution (Ritcey et al., 1983). Oxidation effect could be achieved by pyrolusite (MnO_2) which exists also as a major oxide in the two operated samples (0.02 and 0.01%) respectively as in the flowing equation.

$2Fe^{2+} + MnO_2 + 4H^+ \longrightarrow 2Fe^{3+} + Mn^{2+} + 2H_2O$
$UO_2 + 2Fe^{3+} \longrightarrow UO_2^{2+} + 2Fe^{2+}$
$UO_2 + Fe_2(SO_4)_3 \longrightarrow UO_2SO_4 + 2FeSO_4$

On the other hand, El Missikat sample contains some deleterious elements such as Ti, Mo, Th, Pb and Zr at relatively higher to trace level than GII ore sample, and might cause either chemical poisoning and/or physical fouling in case of uranium recovery by ion exchange resin. So that, the leaching solution concentration should be lower than 100mg/L to avoid their dissolution. As Fe^{+3}/Fe^{+2} ratios greater

than 2, no need for adding oxidant to achieve uranium dissolution reaction (Ritcey and Ashbrook, 1982; Ritcey, 1989).

Presence of silicate and iron oxide as gangue minerals lead to consume sulfuric acid during initial reactions. K-feldspar, Na-feldspar, Ca-plagioclase and Biotite breakdown to Ortho-silicic acid, H_4SiO_4, and various metal cations such as Na^+, K^+, Ca^{2+}, Fe^{2+}, and Fe^{3+}. The ferric ion concentration in leach liquor is controlled by adjusting the redox potential by the addition of oxidant. For typical leaching conditions the relationship between the redox potential and the iron concentrations is given by the Nernst equation (Sommar et al., 1973).

$$Ec = 397 + 0.19847\ T \log ([Fe^{3+}]/[Fe^{2+}])\qquad(1)$$

Where Ec is the solution potential relative to the saturated calomel electrode at 35°C, (mV) is the molar concentration and T is the temperature (K). Equation (1) shows that at an oxidation potential of 400 mV about 50% of the iron is in the ferric state, while at 500mV only 2% remains as ferrous ion (Ritcey, 1989).

Heap leaching technique produce a huge amounts of pregnant leach solution which is difficult to pretreatment before loading, so the required low H_2SO_4 concentrate to keep the resulting leach at pH should not exceed 1.5. In addition to decrease the solubility of other associated elements (Madakkaruppan et al., 2019).

Grain Size Analysis of Mineralized Sample

Uranium distribution was investigated in the study samples for each grain size faction, Table 2 shows the granulometric analysis and uranium distribution for determining the most suitable size to achieve the aim of the study.

Table 2. Granulometric analysis and uranium distribution in the sample.

Size (mm)	GII			El_Missikat		
	Fraction weight, (g.)	Size distribution wt.%	Assay of Uranium, ppm	Fraction weight, (g.)	Size distribution wt.%	Assay of Uranium, ppm
+1.25	140	14.0	70	140	14.0	41
-1.25 to +0.5	437	43.7	122	437	43.7	33
-0.5 to +0.25	180	18.0	149	180	18.0	9.4
-0.25	245	24.5	350	245	24.5	17
Total	1002	100.2	172	1002	100.2	100.4

Relevant Factors Affecting Uranium Leaching From Gattar and El Missikat

A series of experiments were designed to study in detailed the effects of several variables on uranium leaching from Gattar and El Missikat technological samples such as acid consumption, solid\liquid ratio, grain size, contact time, and PLS pH. These are shown in Figure 1.

Acid consumption

From the obtained data shown in Figure 1a, it is clear that, the uranium leaching efficiency increases as periodically from 35 to 92%, as the acid concentration of leach solution increases from 10 to 50g/L, then tends to be stable after that. On other hand, behavior shows considerably increase in uranium leaching efficiency (17 to 94) with lower increase in acidity (5 to 40g/L). From these data, it is concluded that the iron content in the ore sample play important role in the leaching efficiency, which accelerate the uranium dissolution with lower acid need. Figure 1b shows more data which verify the above conclusion. Since, the redox potential increases in leaching process more rapid in El Missikat than GII ore sample. From these data, it is concluded that an economically 40 and 50g/L acid concentration is the best one for El Missikat and GII respectively. Thus, we avoid dissolution the elements that causes resin poisoning.

Effect of agitation time

Leaching experiments were performed over a range from 30 to 200 min. Other variables were fixed at the leaching conditions of 40g/L sulfuric acid, 1/2 solid/liquid ratio, at 25°C temperature and grain size of -0.25mm. The obtained data show that uranium leaching efficiencies increase with increasing contact time achieving its maximum after 120min. Increasing time over 120 min was found to be ineffective as shown in Figure 2.
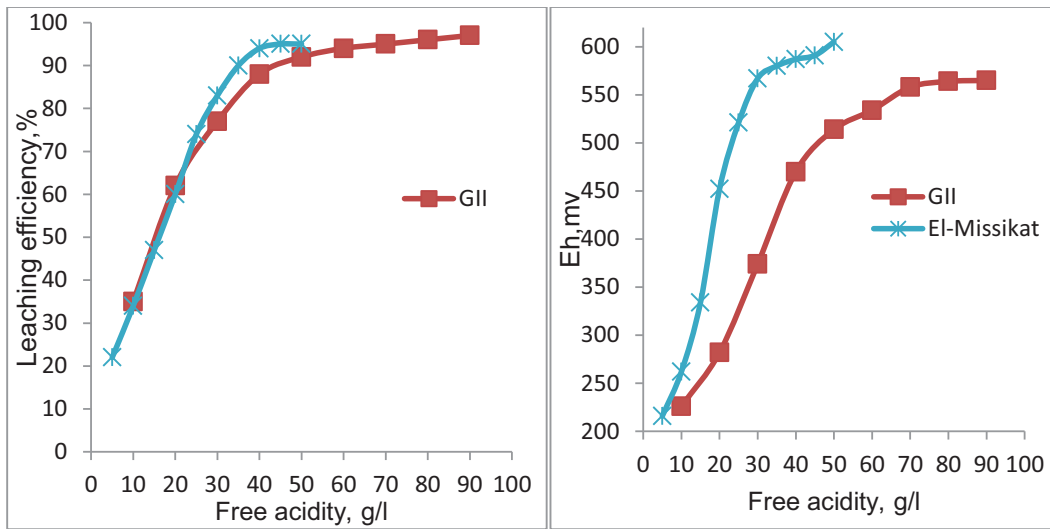
Figure 1. Effect of **a)** free acidity   **b)** Eh on leaching of uranium.
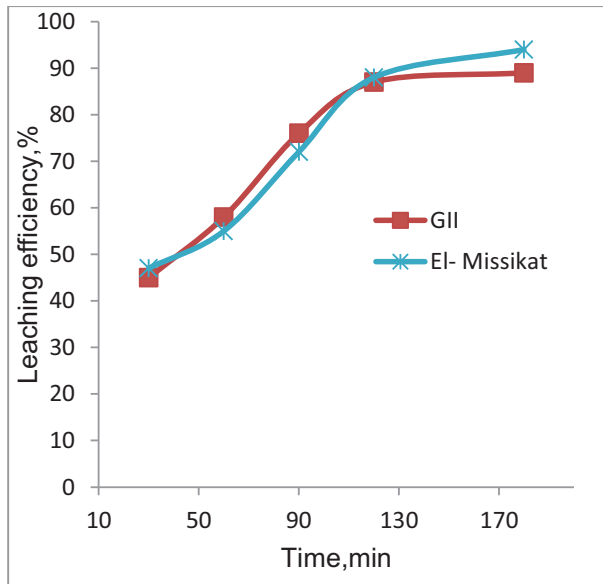

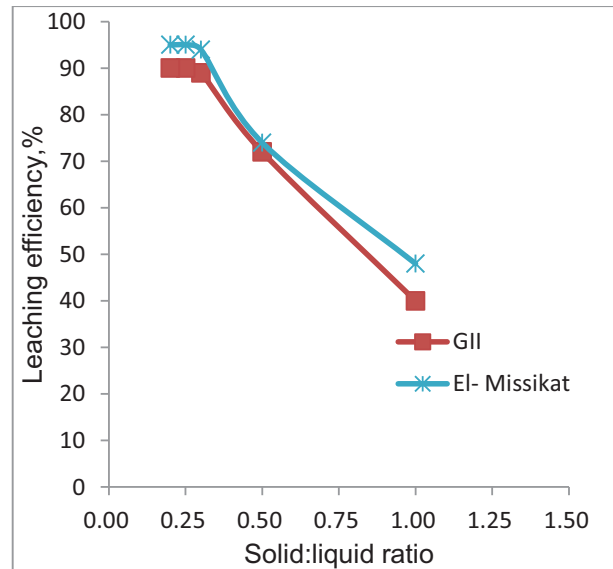**Figure 2.** Effect of contact time on uranium leaching efficiency.

Figure 3. Effect of solid: liquid ratio on uranium leaching efficiency.

Solid/liquid ratio

As in shown in Figure 3, the effect of solid/liquid ratio on the dissolution of uranium was studied using 1:1, 1:2, 1:3, 1:4 and 1:5 solid/liquid ratios. From these data, it was found that beyond 1/3 S/L ratio, only slight steady increase in the leaching efficiencies of uranium was achieved. Accordingly, a solid ratio of 1/3 would be considered as optimal ratio at which the uranium leaching efficiency of attained 89 and 92% for El Missikat and GII, respectively.

Effect of Grain size

The effect of the grain size on the uranium leaching efficiency is achieved by studying the grain size of mineralized samples ranged from +1.25 to -0.25 mm. Other leaching conditions were fixed. The results obtained are presented in Figure 4. It can be seen that uranium leaching efficiency increased from 48 to 89% and 52 to 94% for El-Missikat and GII, respectively with decrease in the crashed size from +1.25 to -0.25 mm. This can be explained by the fact that by decreasing the grain size, the surface area
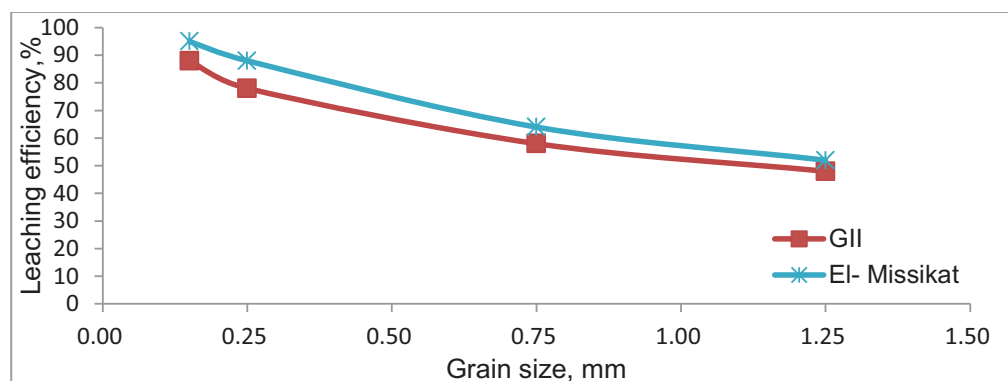
Figure 4. Effect of grain size of ore sample on uranium leaching efficiency.
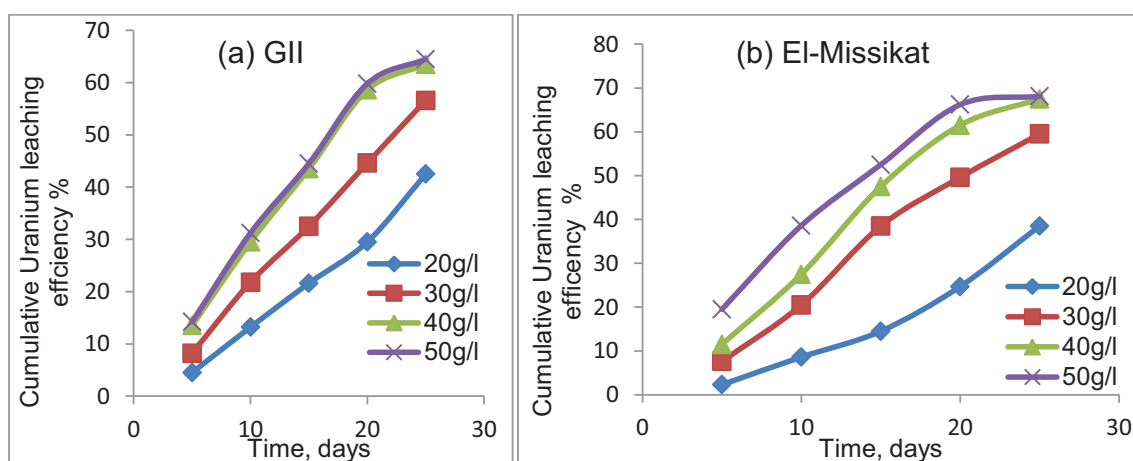

Figure 5. Effect of free acidity on uranium leaching efficiency during column leaching of GII and El Missikat.

exposed to the reaction increases and hence the percentage of extraction also increases.

Column Percolation Leaching
Column leaching (5.0cm diameter and 100cm high) experimental was performed to study the effect of the following parameters on uranium dissolution and acid consumption: Ore particle size, application rate, lixiviant acid concentration, ore height, and ore grade. The experiment was expected to generate a reduction in acid consumption without affecting uranium dissolution.

Free acidity effect
The effect of the H_2SO_4 concentration was studied from 20 to 50g/L on the uranium leaching efficiency on column during day 25 at room temperature with -0.25 mm. The derived plotted Figures 5 (a, b) shows that the same result was obtained on the batch experiment. Since, the uranium

increase with free acidity increase and tend to be stable as free acidity increase from 40 to 50g/L.

Effect of Grain size
In this type of leaching the columns were packed with differing the particle size from +1.25 to -0.25 mm with fixing the other conditions, 30g/L H_2SO_4 and 1/3 solid liquid ratio were achieved during day 25. Their plotted Figure 6 (a, b) show the directly increase in uranium leaching with decrease in the particle size which owing to the increase in the particle surface area at which the reaction takes place.

Kinetic Reactions of Column Leaching
As shown in previous figures there are evidence that the mechanism of leaching of the short-time (batch experiment) is different from that of the long-time (column experiment). Since the slopes for the curves at these periods (120 min for batch and day 25 for column) are noticeably different.
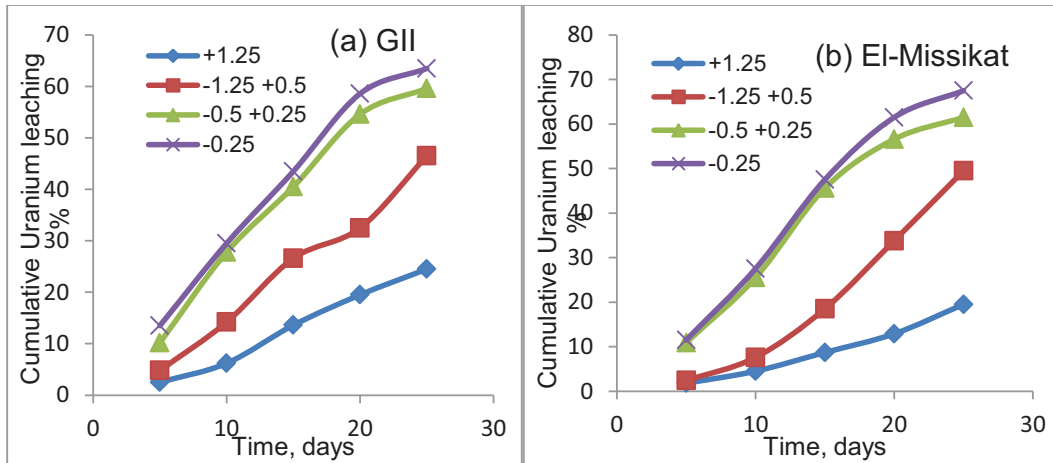
Figure 6. Effect of grain size on uranium leaching efficiency during column leaching of GII and El Missikat.

The dissolution kinetics of uranium was studied to understand the rate-controlling step and to optimize the leaching process. As uranium leaching is a heterogeneous reaction including more than one phase, specifically fluid and solid phase, shrinking core model (SCM) for spherical particles of unchanging size can be used to study the kinetics. With respect to the study of the liquid–solid reaction kinetics, many different mathematical models of kinetic reactions, such as the unreacted core shrinking model, and the particle model, have been proposed. One of the most important models is the unreacted core model, which has been successfully and extensively used (Sililo, 2016; Kusrini, et al. 2018).

Based on the research results of Ekinci (1998), the uranium ore leaching fractal dynamics can be studied with the unreacted core model and the reaction as shown below:

$$A_{(fluid)} + B_{(solid)} \longrightarrow Products$$
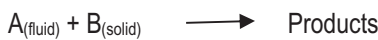
If the action is controlled by a chemical reaction, the reaction kinetics is given as follows:

$$1-(1-X)^{1/3}=K_1t \qquad (2)$$

Where X is the ratio of the accumulated amount of the leached uranium to the total content of uranium in the ores, and K is the uranium dissolution rate (g d^{-1}).

If the action is controlled by diffusion through a metal-ore surface, then the reaction kinetics equation can be written as follows:

$$1-3(1-X)^{2/3}+2(1-X)=K_2t \qquad (3)$$

Applying a regression analysis to the tested data by using these equations, it is found that the rate of the uranium

metal dissolution is controlled by the chemical reaction and the diffusion reaction. Based on the leaching results of two mineralized samples, the integrated rate values of the leaching for every tested sample are described by equations (1) and (2) and shown in derived figures.

Effect of free acidity
Figures 7a (GII and El Missikat) derived from pervious column tested results, show that 30g/L H_2SO_4 is the excellent concentration for applying the column leaching in two mineralized samples on the basis of chemical reaction model.

On basing the diffusion model as shown in Figures 7b (GII and El Missikat), the situation differ than in chemical model. Since, the 40 and 50g/L are preferred concentration for GII and El Missikat mineralized samples respectively. Thus, the speed of the uranium dissolution reaction increases, and the chemical reaction control occurs much earlier than the diffusion reaction control in the leaching experiment.

In order to obtain the reaction order for the total H_2SO_4 concentration, log-log plots of the rate constants versus the total H_2SO_4 concentration are plotted and given in Figure 8. The reaction order was determined to be about 0.920 and 0.983 for GII and El Missikat mineralized samples respectively, which indicate strong dependence of the rate on H_2SO_4 concentration.

Effect of Grain size
Figure 9a shows the integrated rate values of the leaching kinetic for the mineralized samples with different fractal dimension based on the chemical reaction control model. The reaction rate reaches a maximum value after day 20, where showed excellent result at (-0.5 to +0.25) and -0.25 mm in case of GII and El Missikat mineralized samples
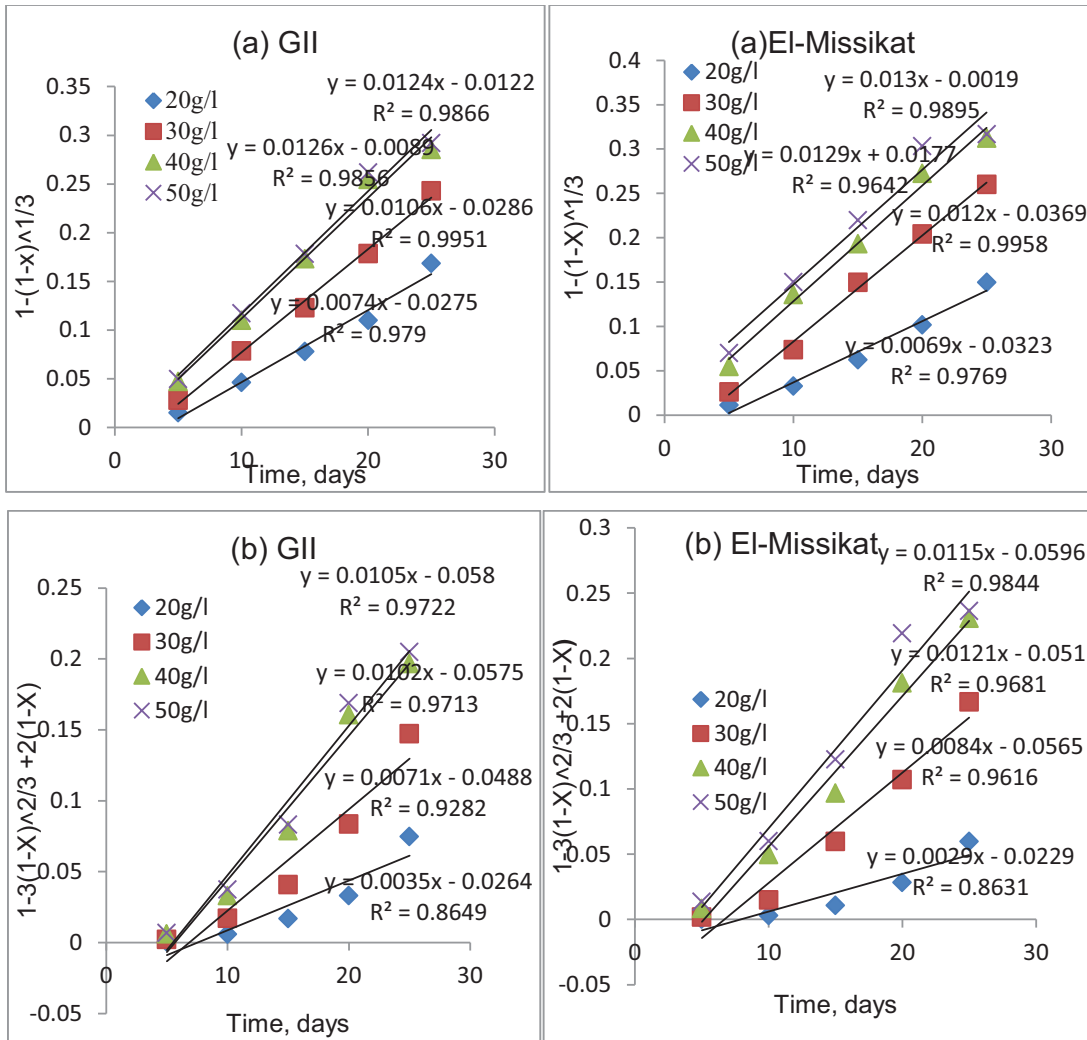
Figure 7. The kinetic curve of uranium leaching with different H_2SO_4 concentration based on different models. **(a)** Chemical reaction control **(b)** Diffusion reaction control.
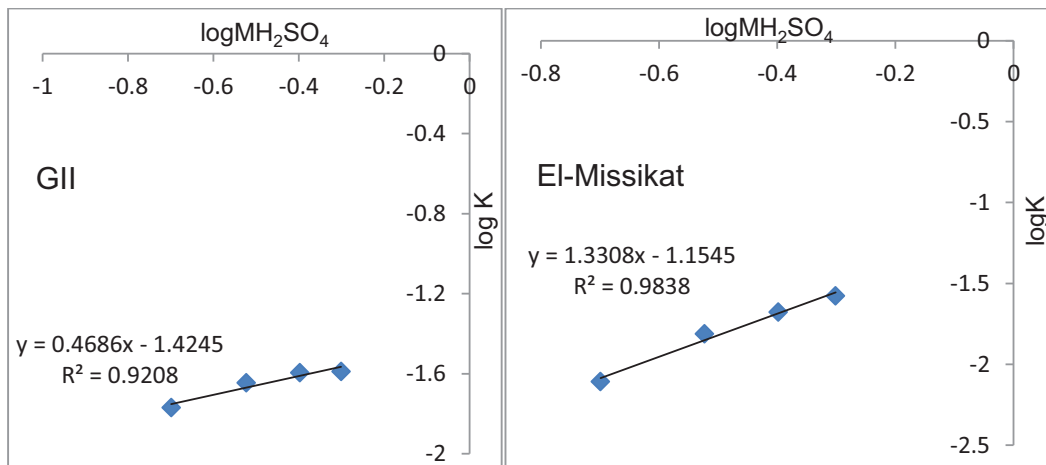

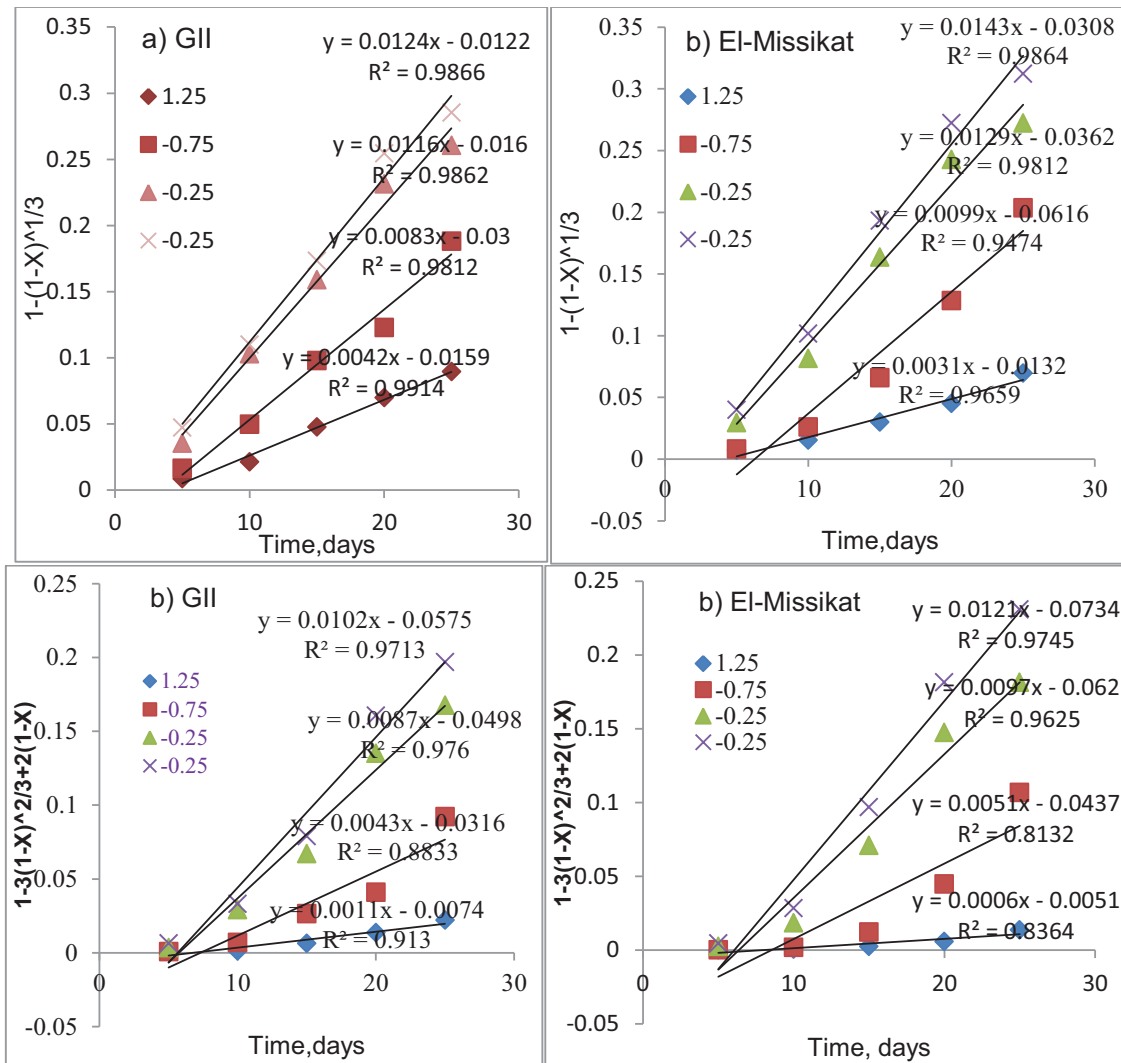**Figure 8.** Log-log plot of the rate constant versus H_2SO_4 concentration.

Figure 9. The kinetic curve of uranium leaching with different particle size based on different models. **(a)** Chemical reaction control; **(b)** diffusion reaction control.
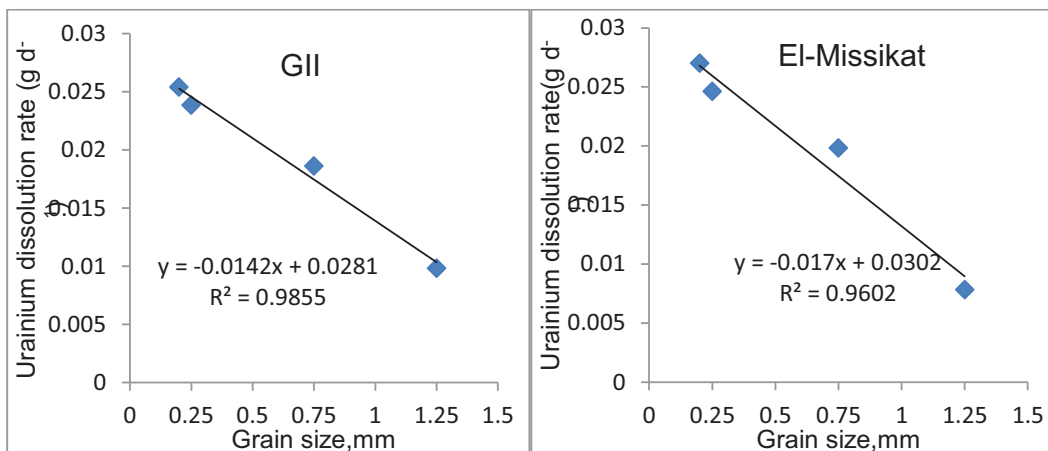

Figure 10. Plot of the Uranium dissolution rate constant versus the average of the particle size.

respectively. These give the higher slops 0.986 for two sizes of two mineralized samples.

Figures 9b which is based on the surface diffusion reaction control model shows lower slopes of dissolution rate curve than the other chemical reaction control model. This can be attributed to the dependence of uranium dissolution rate on surface diffusion reaction control than the chemical one. However, as the chemical reaction goes on, the heat of the chemical reaction is accumulated and the movement of the molecular collision becomes aggravated, then the leaching solution diffuses into the nucleus of the ores gradually. Then afterwards, the diffusion reaction rate also increases gradually.

The apparent rate constant was determined and plotted against the initial average particle size and the results are shown in Figure 10. The linear relationship between the rate constant K, and the particle size indicates that the ash layer diffusion reaction on the particle surface is the rate-limiting step of the dissolution process. As shown in Figure 10, GII mineralized samples gives higher slop than that of El Missikat, which indicates that GII ore samples gives higher dissolution rate with particle size decrease than El Missikat.

CONCLUSION

The potentiality of heap leaching of uranium from low grade uranium mineralization of GII and El Missikat were investigated via batch and column tests. Kinetics models were applied on column leaching tests to understand the rate-controlling step and to optimize the leaching process. On the basis of chemical reaction model, 30g/L H_2SO_4 is the excellent concentration for applying the column leaching in two mineralized samples, while on basing the diffusion model, the situation differ than in chemical model. Since, the 40 and 50g/L are preferred concentration for GII and El Missikat mineralized samples respectively. Thus, the speed of the uranium dissolution reaction increases, and the chemical reaction control occurs much earlier than the diffusion reaction control in the leaching experiment. Surface diffusion reaction control model shows lower slopes of dissolution rate curve than other of the chemical reaction control model.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCE

Amer, T. E., Ibrahim, T. M. & Omar, S. A. (2005). Micro-probe studies and some rare metals recovery from El Missikat mineralized shear zone. Eastern Desert, Egypt, 4th International Conference of the Geology of Africa, 2:225-238.

Amin, A. E., Kamal, H. M., Ghazala, R. A. & Awad, L. S., (2017). Recovery of Uranium from the Mineralized Shear Zone of Jabal El Missikat, Eastern Desert, Egypt. Quest Journals: Journal of Research in Environmental and Earth Science, 3(5):8-19.

Attawiya, M. Y. (1984). Geochemistry and genesis of the uranium mineralization of G. El Missikat, Egypt. Annual Geological Survey Egypt 13:67-74.

Bouffard, S. C. & Dixon, D. G. (2001). Investigative study into the hydrodynamics of heap leaching processes. Metallurgical and Materials Transactions B 32(5):763-776.

Dabbour, G. A. (1989). Minerals laleutifization in a uranium occurrence in G. Gattar, International Report of the Nuclear Material Authority (NMA).

Davies, W. & Gray, W. (1964). A Rapid and Specific Titrimetric Method for the Precise Determination of Uranium Using Iron (Ii) Sulphate As Reductant; Talanta, 11:1203-1211.

Ding, D., Liu, Y. & Hu, N. Y. (2012). Two Stage Column Leaching of Uranium from Uraninite Ore. Journal of Computational and Theoretical Nanoscience 5(1):96-100.

Ekinci, Z., Colak, S., Cakici, A. & Sarac, H. (1998). Leaching Kinetics of Sphalerite With Pyrite In Chlorine Saturated Water. Mineral Engineering 11:279-283.

Ibrahim, T. M. (2002). Geologic and radioactive studies of the basement-sedimentary contact in the area west Gabal El Missikat, Eastern Desert, Egypt". PhD. thesis, Mansoura University, El Mansoura, Egypt, p. 214.

Kamal, H. M. (1995). Study on the Distribution and Recovery of Uranium/Molybdenum From Their Minerals From Gable Gattar Area, Eastern Desert, Egypt: M.Sc. Thesis, Faculty of Science, Cairo University Egypt.

Kusrini, E., Nurani, Y. & Bahari, Z. J. (2018). Extraction of rare earth elements from low-grade Bauxite via precipitation reaction. IOP Conference Series: Materials Science and Engineering p. 334.

Lupo, J. F. (2009). Liner system design for heap leach pads. Geotextiles and Geomembranes, 28(12):163-173.

Madakkaruppan V., Pius, A., Sreenivas, T. & Sunilkumar, T. S. (2019). Behaviour of Si, Al, Fe and Mg during oxidative sulfuric acid leaching of low grade uranium ore: A kinetic approach, Journal of Environmental Chemical Engineering 7:103-139.

Mahdy, M. A., Salman, A. B. & Mohamed, A. H. (1990). Leaching studies on the uraniferous Hammamat sediments, wadi Belih, Northern Eastern Desert, Egypt, 14th CMMI Cong., Edinburgh, p.229-235.

Mahmoud, K. F., Chen, X., Ibrahim, M. S., Li, J., Mahfouz, M. G., Li, W. & Nagar, M. S., (2001). Final Report On Gattar Experimental Yellow Cake Production Unit, Chinese & Egyptian Experts, Scientific Internal Report, Nuclear

Materials Authority (NMA), Cairo, Egypt.

Mahmoud, K. F. (2000). Mineralogical and geochemical characteristics of some uranium occurrences in Gabal Gattar area as basis for preparation of high –grade uranium concentrate, Ph.D. Faculty of Science, Ain Shams University, Cairo, Egypt.

Marczenko, Z. (1976). Spectrophotometric Determination of Elements. New York: John Wiley & Sons Inc.

Mohamed, N. A. (1995). Distribution and extraction of uranium and some trace elements from the mineralized El Missikat – El Erediya areas, Eastern Desert, Egypt. Ph.D. Thesis, Cairo University.

Mousa, M. A., Daher, A. M., Omar, S. A., Khawassek, Y. M., Haggag, S. A. & Gawad, E. A. (2014). Kinetics of leaching process of uranium from El Missikat shear zone Eastern Desert, Egypt. Journal of Basic and Environmental Sciences 1:65-75.

Nagar, M. S., Kamal, H. M., El Monsif, A. M. & Ghazala, R. A. (2020). Potential uranium recovery by percolation leaching from El Missikat mineralized silica vein, Eastern Desert, Egypt. Academic Journal of Environmental Science 8(5):71-80.

Ritcey, G. M. & Ashbrook, A. W. (1982). Solvent Extraction: Principles and Applications to Process Metallurgy, Vol. 1 and 2, Elsevier, Amsterdam and New York.

Ritcey, G. M. (1989). Tailings Management-Problems and Solutions in the Mining Industry, Elsevier, Amsterdam and New York, p. 970.

Ritcey, G. M., Haque, K. E., Lucas, B. H. & Skeaff, J. M., (1983). Uranium Ore Processing, US Patent 4,374,096, US Govt Printing Office, Washington DC.

Sililo, B. (2016). Modeling uranium leaching kinetics, Department of Material Science and Metallurgical Engineering, Faculty of Engineering, Built Environment and Information Technology, (Msc thesis) University of Pretoria, South Africa.

Sommar, G., Omrod, G. T. W. & Chaix, R. P. (1973). Recent Developments In The Instrumentation And Automation Of Uranium Processing Plants, Journal of South African the Institute of Mining and Metallurgy, 74:413-420.