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# Kinetics of uranium bioleaching in stirred and column reactors

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ABSTRACT

A fundamental study on the kinetics of uranium mineral bioleahing using *Acidithiobacillus ferrooxidans* has been carried out in stirred reactor (SR) and column reactor (CR). The four factors affecting uranium dissolution kinetic including aeration rate, pH, initial $Fe^{2+}$ concentration and temperature were selected to be optimized in SR. The aeration rate of 100 l/h pH of 1.8, initial $Fe^{2+}$ concentration of 4 g/l and temperature of 35 °C were determined as optimal conditions. To understand ferric and ferrous ions changes by biooxidation, chemical leaching at constant potential were conducted. Results showed that the electrochemical reaction controlled the overall uranium dissolution. By the progress of bioleaching, three stages of bioleaching were observed. The rate controlling is anodic uranium mineral decomposition in the first and second stages while in the third stage cathodic ferric reduction is rate controlling. By using SEM, EDX, XRD and BET analysis, the formation of K-jarosite layer over the residue particles confirmed and the increasing of porosity in the particles surface proved that diffusion of ions from layer was not limiting in uranium bioleaching. The modified kinetic model during bioleaching in SR was presented and developed in CR. Comparing the results, the semi-empirical model data are in good agreement with the experimental data for both uranium leaching and bioleaching in SR and CR.

## 1. Introduction

Low grade ores are treated under very mild conditions to minimize costs. Extraction of uranium from ores by bacterial leaching processes arise from the need to develop economically viable processes for processing low grade ores (Munoz et al., 1995; Ehrlich, 2001). In spite of slow rate of bioleaching process, this technology is attractive as it is not energy intensive. In the uranium bioleaching, bacteria generate $Fe^{3+}$ by oxidizing pyrite to soluble $Fe^{2+}$ or by oxidizing added $Fe^{2+}$ as a main substrate. Then $U^{4+}$ converting into $U^{6+}$ by producing $Fe^{3+}$ in acidic media. The oxidizing sulfur content to sulfuric acid by bacteria decrease pH that requires for the bioleaching reactions (Abhilash and Pandey, 2013a; Boon and Heijnen, 1998). On the other hand, chemical leaching of uranium ore conducted under iron sulfate and sulfuric acid conditions (IAEA, 1993).

Enhancement of low grade resource processing needs to better understand of the kinetics of bioleaching of uranium minerals. A comparison of previous studies about uranium bioleaching in stirred bioreactor is summarized in Table 1. The kinetics of uranium bioleaching was investigated by Abhilash and Pandey (2011) from apatite of Narwapahar mine in shaking flask at 10% (w/v) pulp density, pH 1.7 and 35 °C with the fine particles of < 45 μm size. The activation energy was 31 kJ/mol and showed uranium bioleaching was chemical control and the uranium biorecovery in 40 days was achieved 96%. Abhilash and Pandey (2012) studied uranium bioleaching kinetics from low grade ore of Turamdih mines in shaking flask at 20% (w/v) pulp density, pH 1.7 and 35 °C temperature using < 76 μm particles. The recovery in 40 days was 98%, activation energy was 28.3 kJ/mol and showed uranium dissolution was chemical control. In last both studies, the authors didn't consider the ferric and ferrous concentrations change with time during the bioleaching.

In this study the effective parameters on the kinetics of uranium bioleaching such as aeration rate, pH, initial ferrous concentration and temperature was investigated and optimized. The uranium bioleaching and characterization of residues were evaluated at optimum conditions in stirred and column reactors. In order to quantify the parameters independently, controlled redox potential experiments were conducted. Finally, a kinetic modified model was presented for uranium mineral bioleaching in stirred reactor and developed in column reactor.

## 2. Materials and methods

### 2.1. Ore

A bulk of low grade uranium ore was obtained from the Saghand uranium mine in the center of Iran. The bulk sample was initially

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**Table 1**
Comparison of uranium leaching by *Acidithiobacillus ferrooxidans* in stirred reactor.

| T (°C) | Pulp density (%w/v) | pH | Volume (l) | Aeration rate (l/h) | Agitation speed (RPM) | Time (days) | Uranium dissolution (%) | Reference |
|---|---|---|---|---|---|---|---|---|
| 35 | 10 | 2.5 | 10 | 78 with 6 l/h $CO_2$ | 200 | 20 | 87.30 $U_3O_8$ | Mahmood (1994) |
| 25 | 5.8 | 2 | 6 | 250 | 510 | 6 | 95% | Eisapour et al. (2013) |
| 35 | 10 | 2 | 2 | – | 150 | 5 | 57% | Abhilash et al. (2013), Abhilash and Pandey (2013b) |
| 35 | 20 | 2 | 2 | – | – | 14 | 98.30 | Abhilash and Pandey (2013c) |

**Table 2**
Chemical composition of ore sample.

| Composition | $Fe_2O_3$ | $SiO_2$ | MgO | CaO | $Al_2O_3$ | $K_2O$ | $Na_2O$ | $P_2O_5$ | S | U |
|---|---|---|---|---|---|---|---|---|---|---|
| Content (%) | 42.05 | 26.39 | 22.22 | 2.35 | 2.21 | 0.63 | 0.11 | 0.71 | 2.96 | 0.03 |

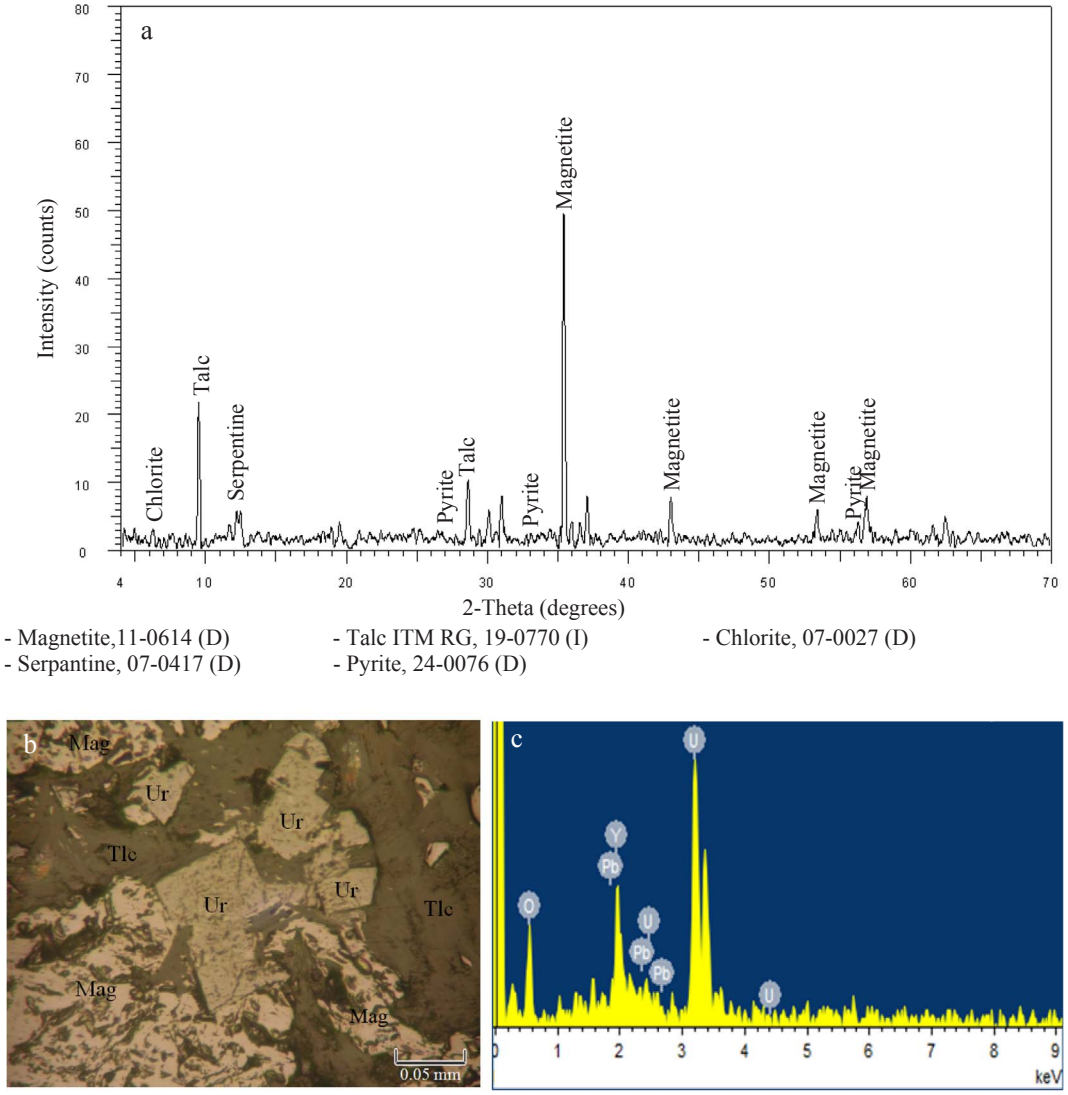


**Fig. 1.** (a) XRD diffractometer of uranium ore, (b) image of uraninite in uranium ore under optical microscope (Ur: Uraninite, Mag: Magnetite, Tlc: Talc) and (c) EDX spectrum of uraninite.

crushed by a jaw crusher from 150 mm top size down to −20 mm. The sample was prepared in particle size of $d_{80}$ = 2.5 mm for column reactor bioleaching and then milled to $d_{80}$ = 100 μm for stirring reactor bioleaching. The chemical composition of the uranium ore is given in Table 2. The X-ray diffractometer (XRD, D8-Advance, Bruker AXS) with the Cu X-ray tube was used to qualitatively analyze the mineral phases at room temperature. The analysis results showed that major minerals are magnetite, talc, serpentine, chlorite and pyrite (Fig. 1a). Mineralogy of ore indicated that the sulfides are mainly presented by pyrite that content in the sample was 5.4%. The uranium oxide most often it is located in the magnetite grains or aggregate is observed as intergrowth with it. The presence of iron containing mineral in the ore and release