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Microbial processing of apatite rich low grade Indian uranium ore in bioreactor

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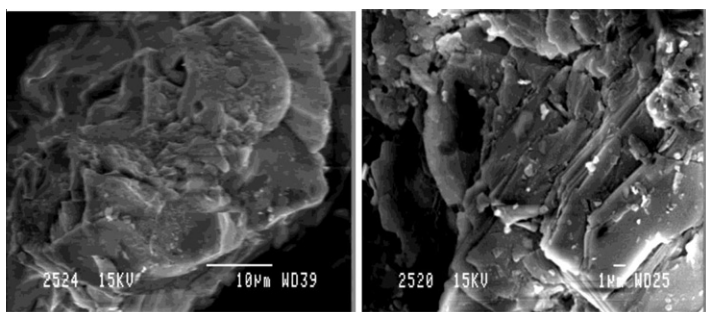
HIGHLIGHTS

- ▶ Bioreactor leaching of uranium by *Acidithiobacillus ferrooxidans* and *Leptosprillium ferrooxidans* improved the kinetics.
- ▶ Uranium leaching was 57% and 63% in 5 days with pure culture of *A. ferrooxidans* and *L. ferrooxidans*.
- ▶ Biogenic Fe(III) with *L. ferrooxidans* and *A. ferrooxidans* leached 90% and 87% uranium in 10 h.
- ▶ Fe(III) biogenically enhances the kinematics of uranium dissolution in bioreactors.

GRAPHICAL ABSTRACT

Leach residues after bioleaching by *A. ferrooxidans* at 35 °C (left) and *L. ferrooxidans* at 40 °C (right) in 10 h.



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ABSTRACT

Bioreactor leaching using enriched culture of *Acidithiobacillus ferrooxidans* and *Leptosprillium ferrooxidans* was investigated for the apatite rich Indian (Narwapahar) uranium ore. Bioreactor leaching of Narwapahar ore of <45 µm size at pH 2.0 and 10% (w/v) PD using 10% (v/v) inoculum of the bacterium at 35 °C (*A. ferrooxidans*) and 40 °C (*L. ferrooxidans*), solubilised 57% and 63% uranium in 5 days, respectively; the E_{SCE} values being 561 and 588 mV. Leaching kinetics improved so much so that ~83% uranium was recovered in just 10 h with 10% inoculum of *A. ferrooxidans* containing biogenic Fe^{3+}; at 20% PD uranium recovery rose to 87%. Role of temperature (25–40 °C) was noticed with 90.3% uranium bioleaching in 10 h at 40 °C with *L. ferrooxidans* as against 77% leaching with *A. ferrooxidans* at pH 2.0, 40 °C and 20% (w/v) PD.

1. Introduction

As of 2010, India had 20 nuclear reactors in operation in six nuclear power plants, generating 4780 MW power (Abhilash and Pandey, 2013) while seven other reactors are under construction and are expected to generate an additional 5300 MW. India is poised to increase the contribution of nuclear power to overall electricity generation capacity from 2.8% to 9% within 25 years (Abhilash and Pandey, 2013). Uranium as energy source, contributing to nuclear reactors in India, was found at Jaduguda (quartz–chlorite–biotite–schist type) in 1951. The first uranium processing plant was commissioned in 1967 at Jaduguda, Jharkhand. Uranium is conventionally recovered from its ores by chemical method following acid or alkali leaching using an oxidant, and is enriched by ion-exchange/solvent extraction process to precipitate magnesium diuranate (Dwivedy and Mathur, 1995; Abhilash and Pandey, 2013). The continued depletion of high grade ores and growing awareness of environmental degradation associated with the traditional methods have provided impetus to explore simple, efficient and less polluting biological methods in uranium mining, processing and waste-water treatments (Dwivedy and Mathur, 1995). Hydrometallurgical methods have some disadvantages such as lower recovery, involvement of high process and energy cost and increase in pollution load of water resources (Dwivedy and Mathur, 1995). For a country with limited energy resources and for long-term

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energy security bioleaching exploiting microorganisms is an alternative, highly selective, eco-friendly and economically attractive option. The procedures are not complicated and are easy to control, and advanced technical knowledge is not required. Moreover, the microorganisms used in this processes are able to grow in acidic environment with high metal content like U, Th, Cu and Ni. *Acidithiobacillus ferrooxidans* was dominant species in the Jaduguda and Turamdih mine waters (Dwivedy and Mathur, 1995; Abhilash and Pandey, 2013).

Uranium ore from the mines of Narwapahar Project, UCIL was investigated by our group to establish its amenability towards bioleaching. Due to the presence of some refractory minerals (Rao and Rao, 1983; Sarangi and Krishnamurthy, 2008), besides being rich in apatite (5%) the Narwapahar ore is commonly reported for the loss of uranium as uranium phosphate during processing (Abhilash et al., 2012). The objective of the work presented in this paper is to study the bioleaching of uranium from Narwapahar ore and optimisation of parameters in bioreactor. This ore in bench scale microbial leaching showed an appreciable uranium recovery of 96–98% in 40 days (Abhilash et al., 2012). On scaling the process to columns, the recovery was 58% in 40 days (Abhilash et al., 2011), though lower, but avoided significant grinding cost of the material. In view of the success in operational Pachuca for uranium leaching, it was considered worthwhile to optimise the microbial leaching of uranium from the ore in a stirred tank reactor (bioreactor).

2. Methods

2.1. Target raw materials

Uranium ores collected in the form of lumps from the mines of Narwapahar were crushed, ground and sieved to get different size fractions. A representative sample of each ore was prepared by coning and quartering for chemical analysis, showed $0.047U_3O_8$, 12.90Fe, $51.24SiO_2$, 0.02Cu, 0.02Ni, 0.01Co, 0.006Mo, $1.81P_2O_5$, $13.8Al_2O_3$, 1.88CaO, 1.07MgO, $0.7TiO_2$, 0.05S (wt.%). The major phases showed the presence of quartz, apatite, alumina and magnetite; whereas, the minor phases showed kyanite, ferrosilite, pyrite, hematite (Abhilash et al., 2012).

2.2. Bacterial species

Mine water sample collected from Narwapahar uranium mines was the source for isolation of *A. ferrooxidans* and *Leptosprillium ferrooxidans* in 9 K media at pH 2.0. The bacterial oxidation of Fe(II) to Fe(III) by was considered as an indication of its growth (Fig. 2.3). The growth of bacteria was also monitored through cell counts in a Petroff–Hauser Counter™ (Fig. 2.4) using Leica™ Biological Microscope. The isolated enriched culture was adapted on 5% (w/v) ore of <100 μm size for three times at pH 2.0 and 35 °C; the adapted culture was used for the bioleaching (Abhilash et al., 2011).

2.3. Experimental procedure

Bio-leaching studies were carried out in a 2 L bioreactor-BIOSTAT-B® (Make-SARTORIUS) at 10–40% (w/v) pulp density of respective ore using 10% (v/v) of enriched bacterial culture. In each case, a known amount of sample was taken and desired pH, stirring speed (150 rpm) and temperature were maintained by PLC based MFCDA™ software controlled operations in the reactor. Experiments were carried out by using bacterial culture and also by biogenically prepared Fe(III) solution. The fresh bacterial culture was adapted on 10 g/L Fe(II) (in a sequence of 5 g/L and 10 g/L Fe(II)) using 10% (v/v) enriched bacterial species in the total volume of 1 L in the 2 L bioreactor under controlled conditions of pH 2.0, 150 rpm and 35 °C. Biogenic ferric sulphate was generated from a synthetic ferrous sulphate solution [10 g/L Fe(II)] at pH 2.0 and 35 °C. The final solution containing Fe(III) enriched with bacterial culture was obtained under this condition in 96 h. The 10% inoculum (biogenically prepared solution) was used to make the slurry with the ore at the desired pulp density for optimization of parameters to understand the role of Fe(III) ions and bacteria. The bioreactor was equipped with a sampling port to withdraw slurry for estimating metal and bacterial concentrations. Ferrous ion concentration was analyzed by titration against N/10 potassium dichromate solution (Jeffery et al., 1989). The pH of the leach slurry in reactor was maintained automatically with 5 M sulfuric acid solution. Redox potential was measured against SCE. Uranium was analysed by Flourimetry (Model-FL-6224™) whereas other metals were analysed by Atomic Absorption Spectrometer-AAS (Model-GBC 908BT™). The quantitative estimate of ferric iron was obtained by deducing from the concentration of ferrous iron (determined by titration) and total iron (determined by AAS). On completion of the experiment, the leach liquor was filtered with Whatman No.42 paper, and the residue was dried in oven and analyzed for residual uranium concentration.

3. Results and discussion

3.1. Uranium bioleaching with enriched (adapted) culture of A. ferrooxidans and L. ferrooxidans

The bioprocessing of Narwapahar ore was investigated in the bioreactor while using the enriched (adapted) culture of *A. ferrooxidans* and *L. ferrooxidans* separately. The experiments were carried out at pH 2.0, 10% (w/v) pulp density and 150 rpm agitation. The sized ore of <45 μm was taken in the slurry with 10% (v/v) inoculum of respective bacterium at 35 °C (*A. ferrooxidans*) and 40 °C (*L. ferrooxidans*). Results in Fig. 1 depict the biodissolution of uranium with change in redox potential in 5 days.

It is noted that nearly 41% and 47% uranium were recovered within 24 h which increased to 57% and 63% by *A. ferrooxidans* and *L. ferrooxidans*, respectively in 5 days with the corresponding redox potential (E) values of 561 and 588 mV. The dissolution of uranium may be accounted for strong oxidizing conditions prevailing in the system which is evident from the high *E* values mentioned above in 5 days. Comparing the similar recovery that was obtained in 15–20 days during the bioleaching in the shake flask

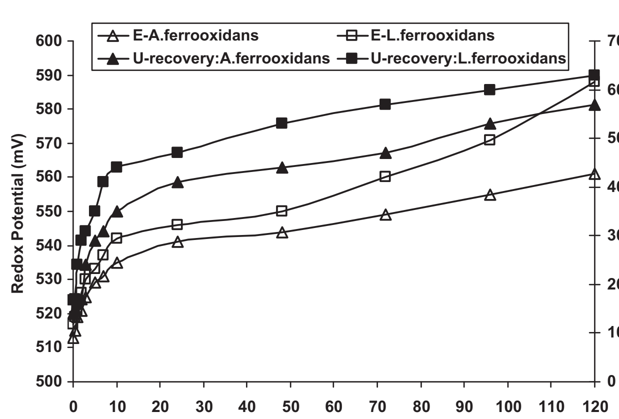

Fig. 1. Uranium biorecovery in bioreactor with variation in redox potential using enriched bacterial culture of *A. ferrooxidans* (35 °C) and *L. ferrooxidans* (40 °C) [Conditions: pulp density: 10% (w/v), particle size: <45 μm; pH: 2.0].