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Bioleaching of Low-grade Uranium ore using Mineral Oxidizing Bacteria - A Review

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Abstract—Uranium is an important natural resource used for the generation of nuclear energy, as the raw material. Extraction of uranium from low -grade ore requires large amounts of energy that is not economic viable and environmentally friendly to extract uranium by chemical leaching as the low grade of uranium ore. So, using a clean technology and economically viable way such as bioleaching for recovery of uranium is very important in uranium mining industry. Bioleaching is the mining of metals from their ores through the use of microbes. This review focuses on the interaction between bacteria and uranium and the possible effects this could have on uranium bioleaching process.

1. INTRODUCTION

Uranium is an important resource used for the generation of nuclear energy [2]. Nuclear energy is a vital constituent of a clean energy strategy. Currently nuclear generation avoids the emission of over two billion tons of carbon dioxide each nuclear power generation capacity [3]. Uranium is commonly understood as a material storing a huge energy and its only commercial application is as nuclear fuel. But apart from its uses in nuclear power plants, the possibility of its use in nuclear weapons makes the material of strategic importance and thereby, restricting its free global trade. The growth of uranium mining normally follows the pattern of growth year [11]. The demand for uranium is ever increasing with the advance of the Nuclear power sector in all over the world, whereas worldwide reserves of high-grade ores are diminishing. However, there exist large stockpiles of low grade uranium ores that are yet to be exploited. In traditional techniques like chemical leaching for extraction of uranium from low -grade ore requires large amounts of energy that is not economic viable and environmentally friendly to extract uranium. So, using a clean technology and economically viable way such as bioleaching for recovery of uranium is very important in uranium mining industry.

1.1 Bioleaching-

Bioleaching processes are alternatives to conventional smelting processes. It is a simple and effective technology for metal excavating from low-grade ores and mineral concentrates. In this process the interaction between metals and microbes with the specific aim of converting insoluble metal sulfides to soluble metal sulpates. Metal recovery from sulfide minerals is based on the activity of chemolithotrophic bacteria, mainly *Acidithiobacillus ferrooxidans* and *T. thiooxidans*, which convert insoluble metal sulfides into soluble metal sulfates [8]. Oxidation of ferrous ion into ferric is one of the Characteristic property of *A. ferrooxidans*. The ferric ion acts as an electron acceptor and convert U^{+4} to U^{+6} state which is soluble in water, hence the metal is leached out to the liquid solution [10].Bioleaching methods are being increasingly applied for metal recovery from low-grade ores and concentrates that cannot be processed economically by conventional methods [8].

1.2 Evolution of uranium bioleaching-

The first commercial production of uranium by bacterial leaching was in 1957 Urgeim, jrica mine, Portugal. Bioleaching has been practiced on an industrial scale in many places in the world and in some countries, it is the main extraction method used. The first operation was uranium bioleaching applied to a virgin ore body in Agnew lake mine Ontario, Canada. Late 1970' surface heap leaching is used for uranium ore mine, but in 1979 cracked ore body led to loss of leach solution and they closed to bioleaching process. In 1984 in Denison mines USA in-situ leaching of uranium ore on 100 ft. lift of ore solution. During last 20 years, USA, Brazil, South Africa and Australia developed Bioleaching process. China has initiated research and field studies on heap bioleaching. The production of Canadian uranium involving some form of bioleaching at between 10%and 20% [7, 8].

2. MICROORGANISM USE IN BIOLEACHING PROCESS-

2.1 Mineral oxidizing bacteria-

A variety of mineral oxidizing bacteria readily found can easily oxidize iron and sulfur containing minerals. This include the iron and sulfur oxidizing bacteria.

2.1.1 Iron oxidizing bacteria- Iron oxidizing bacteria gain their energy for growth from the oxidation of ferrous iron to ferric iron. *Leptospirillum ferrooxidans* and *Leptospirillum* *ferriphilum* bacteria are used in bioleaching process of low grade ores. *Leptospirillum ferroxidans* is another acidophilic obligately chemolithotrophic ferrous iron oxidizing bacterium, which was first isolated by Markosyan from mine waters in Armenia.

2.1.2 Sulfur oxidizing bacteria-

Sulfur oxidation is the process by which microorganism convert hydrogen sulfide into elemental sulfur by partial oxidation or sulfate. The levels of oxidation are hereby dependent on the oxygen concentration. Sulfur oxidizing bacteria are used for a variety of application to reduce the amount of hydrogen sulfide. *Acidithiobacillus thiooxidans* and *Acidithiobacillus caldus* are also used in bioleaching process of low grade ores.The most important in the bioleaching process is Acidithiobacillus ferrooxidans. It is a chemoautotrophic acidophile, meaning that it obtains its energy from inorganic sources and

3. BIOLEACHING MECHANISM-

A generalized reaction can be used to express the biological oxidation of a mineral sulphide involved in leaching:

$MS + 2O_2 \rightarrow MSO_4$ (1)

There are two mechanism of bioleaching.

3.1 Direct leaching-

One involves physical contact of the organism with the insoluble sulphide. Its means a direct electron transfer metal sulfide to the cell attached to the mineral surface.

3.2 Indirect leaching-

The other involves**,** the ferric- ferrous cycle**.** Indirect leaching proceeds via the metal sulfide oxidizing agent Fe^{+3} which is generated by Fe^{+2} oxidizing bacteria either planktonic or attached to the mineral surface.

3.3 Bioleaching of uranium-

Uranium leaching proceeds by the indirect mechanism as bacteria dose not directly interact with uranium minerals. The role of Acidithiobacillus ferrooxidans in uranium leaching is the best example of the indirect mechanism [9]. The uranium solubilization by indirect mechanism can be described as:

$FeS_2 + H_2SO_4 \rightarrow 2\ FeSO_4 + H_2O + S^{\circ}$ (2)

$FeSO_4 + H_2SO_4 + O_2 \rightarrow Fe_2\ (SO_4)_3 + H_2O$ (3)

The Fe (II) can be re-oxidized by microbes to Fe (III) which takes part in the oxidation process again. Sulfur formed is simultaneously oxidized depending on the species to H_2SO_4 which aid (oxidizing agent) the dissolution of uranium as follows:

$2S^{\circ} + 3O_2 + 2H_2O \rightarrow 2\ H_2\ SO_4$ (4)

The insoluble uranium is oxidized to the water soluble uranium sulphate as:

$UO_2 + Fe_2\ (SO_4)_3 \rightarrow UO_2\ SO_4 + 2\ FeSO_4$ (5)

4. TYPE OF BIOLEACHING-

4.1 In situ leaching

In situ leaching of metal involves drilling boreholes into the ore deposit. Pumping a bioleaching solution and air under pressure into a mine or into ore bodies made permeable by explosive charging. The resulting metal enriched solutions are recovered through wells drilled below the ore body (Fig 1).This method is applicable only to sandstone-hosted uranium deposits located below the water table in a confined aquifer. The growth of microbial populations during in situ leaching is believed to be one of the causes of flow path plugging in the ore body, which results in decreased uranium production [9].

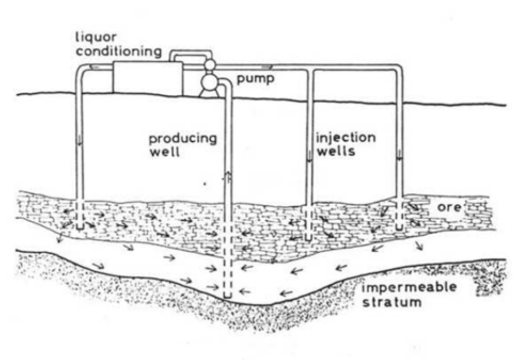

Fig. 1: In-Situ Leaching process.

4.2 Dump leaching

Dump leaching is the oldest process. The size of dumps varies considerably and the amount of ore may be in the range of several hundred thousand tons of ore. It is involves uncrushed waste rock which is piled up (Fig 2, 3).

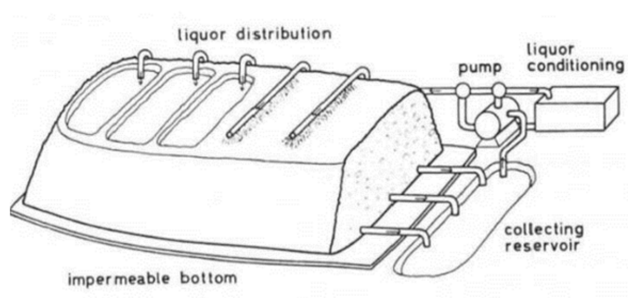

Fig. 2: Dump leaching Process-on ore bed.

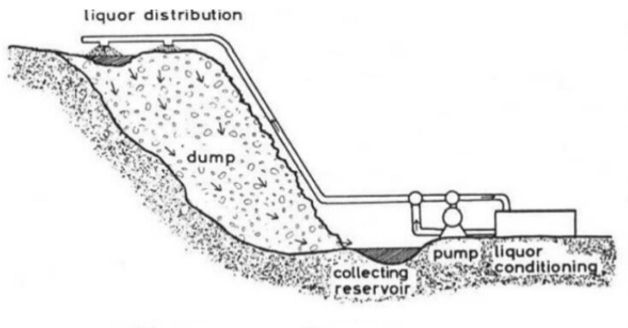

Fig. 3: Dump leaching Process-on slope.

4.3 Heap leaching

In this process requires the preparation of the ore, primarily size reduction, so as to maximize mineral-lixiviant interaction and the laying of an impermeable base to prevent lixiviant loss and pollution of water bodies. (Fig4)

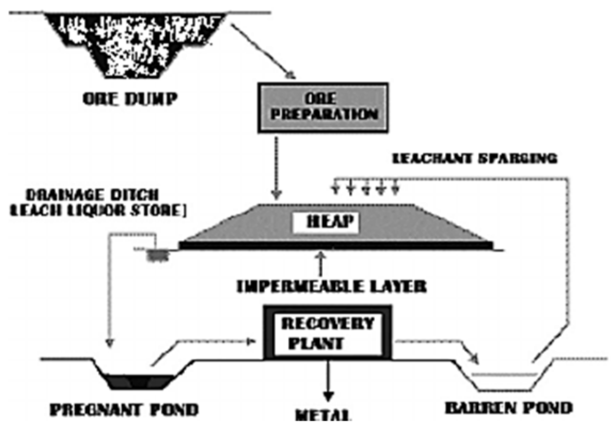

Fig. 4: Heap leaching Process.

5. ADVANTAGES OF BIOLEACHING-

- Bioleaching is simpler, cheaper to operate and maintain.
- It can be used extract metals from ores that are too poor for other technologies.
- The bioleaching process is more environmentally friendly than traditional extraction methods.
- Bioleaching if used for all ore leaching processing could drastically reduce the amount of greenhouse gases in our atmosphere.

6. CONCLUSIONS AND FUTURE APPLICATION-

At present, bioleaching is being used recovery of low grade uranium ore use commercial bioleaching process like in situ leaching, heap and dump leaching process all over the world. The application of microorganisms for low grade uranium ore processing and waste remediation is likely to become increasingly important in Indian context in the future. The use of iron and sulfur oxidizing bacteria to recover metals like uranium in low grade uranium ore, now well established. In the immediate future. In- situ bioleaching is likely to be a major area of expansion while using thermophilic bacteria. Bioleaching to replace the many traditional uranium mining process in not too distant future.

7. ACKNOWLEDGEMENTS

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