Bioleaching: An Important Approach for Metal Refinement-A Review

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ABSTRACT---- ***Bioleaching is a new method of refining minerals from their parent ores in order to obtain the required metal using naturally occurring microorganisms. These microbes are naturally attached to the mineral ores, they used inorganic carbon as their source of carbon, and they flourished in a low pH environment. Usually activated and cultured in irrigated heap and stirred tank reactors. The environment within the reactors must be highly aerated, very acidic and in addition, temperature, carbon dioxide (CO_2) and presence of toxic elements or compounds are essential for the development of these microbes. The microorganisms work on the mining waste and dissolved the mineral into solution which is sent to the solvent extraction and electrowinning units where the metal is recovered at the cathode. Metals such as Copper, Gold, Silver, Uranium, Zinc, Nickel etc are now recoverable using Bioleaching process in many mining companies around the world.***

Keywords---- Bioleaching, Metals, Microorganisms, Reactors,

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1. INTRODUCTION

Conventional mineral extraction methods rely on the application of toxic chemicals in the presence of extremely high temperatures which often leave behind a legacy of environmental destruction, illness and death. These factors have prompted the pursuit of cleaner and safer mineral extraction methods which are more in line with the rapidly increasing global drive towards green solutions. "Bioleaching" an aspect of biotechnology has become one of the promising options because it involves totally natural biological processes for its efficacy. It only needs little intervention to activate the microorganisms which are naturally attached to the mineral ores. It requires no external fuel source and produces no toxic byproducts and emissions.

Bioleaching is a method of extracting minerals and metals from their parent ores using naturally occurring biological processes. The practice requires none of the environmentally damaging processes found in conventional refining methods and instead relies entirely on the natural interaction of biological organisms. The process has also proven to be effective at viably extracting minerals from low grade ore and tailings previously considered as waste. Biological refining of minerals shows great promise in the processing of a range of elements such as the extraction of Copper, Gold, Uranium, Nickel, Cobalt etc from their ores.

Bioleaching is regarded as a "Green Technology" that will become even more important in future years, as it avoids much of the energy costs and carbon footprint associated with conventional mining. Although extracting metals using bacteria is much slower than roasting ores, the bacteria "work for nothing" as they actually use the energy present in the minerals themselves. As an added bonus, they take carbon dioxide from the air (like green plants) and, therefore, help to counter the problem that is acknowledged to be behind climate change (Barrie Johnson 2011).

Bioleaching consist of two related microbial processes: bacterial leaching, also known as bioleaching, and biooxidation. The term leaching generally means the solubilization of one or more components of a complex solid by contact with a liquid. In bacterial leaching, the solubilization is mediated by bacteria. So bacterial leaching is a process by which the metal of interest is extracted from the ore by bacterial action, as in the case of bacterial leaching of Copper. On the other hand, biooxidation implies the bacterial oxidation of reduced sulfur species accompanying the metal of interest, as in the biooxidation of refractory Gold minerals (Pyrite).

This article discusses many of the practical considerations concerning the development of less expensive; partially controlled; irrigated heap or dump reactors and describe the specification of solvent extraction and electro winning processes.

2. THE MICROBIOLOGY OF BIOLEACHING

The discovery of iron and sulphur oxidizing bacteria in hot springs in the late 1960s by Brierly and Brock has made it possible to carry out bioleaching at considerably higher temperatures. In genetic studies in 1996, these microorganisms turned out not to belong to the common bacterial group but to belong to an entirely different branch of the Tree of Life called Achaea under the domain of acidophiles (Backstrom, 2013).

These microorganisms are autotrophic, that is, they use inorganic carbon (CO_2) as carbon source for their life processes and also take carbon dioxide from the air (like green plants) which is very important in the solving the problem of atmospheric carbon dioxide accumulation and hence reduce its effect on climate change. They are acidophilic which means they flourish in the pH range 1 – 3 (Backstrom, 2013) (Rawlings and Johnson, 2007). These microorganisms are naturally found in the mining sites attached to the mineral ores.

3. FACTORS AFFECTING THE OPTIMUM GROWTH OF MICROBIAL CANDIDATES OF BIOLEACHING

Irrespective of where they are found, the microorganisms that can be used to achieve Bioleaching processes are required to grow in an essentially inorganic, highly aerated and low pH environment (Rawlings and Johnson 2007). In addition, temperature, carbon dioxide (CO_2) and presence of potentially toxic elements or compounds are also necessary for the development of Bioleaching micro organisms (Backstrom, 2013).
Depending on the temperature range in which the Bioleaching micro organisms have their optimal growth, they are divided into different classes. Table 1.

Table 1: Classes of Bioleaching Microbes based on Temperature Range

Classes	**Temp. (^oC)**
Psychrophiles	20
Mesophilles	35 – 42
Moderate Thermophiles	45 – 50
Extreme Thermophiles	65 – 80

Source: (Backstrom, 2013)

These bioleaching microbes are usually triggered and cultured in two ways: simplify, partly controlled, less expensive, irrigated heap or dump reactors and sophisticated, highly controlled, expensive stirred tank reactors.

Dump or heap reactors range from randomly packed, low efficiency dumps to carefully designed heaps that are stacked, aerated, irrigated and sometimes thermally insulated for higher levels of mineral leaching efficiency. Dump and heap reactors are typically used for leaching low grade rocks or tailings that would otherwise be discarded as waste or for low value mineral ores that do not allow for the use of expensive reactors (Rawlings and Johnson, 2007).

Stirred tank reactors consist of a series of aerated continuous flow tanks that are used mostly in a pretreatment process for the recovery of high value metals, such as gold, from mineral concentrates. These reactors are more expensive to construct and operate than heap reactors but, allow for the precise control of parameters such as temperature, pH and aeration, all of which have a major impact on the microbial populations and metal recovery efficiency.

Sometime, good conditions that favoured the growth of these bioleaching microbes can also be attained at the abandoned mine sites. However, in this case, these same micro organisms can also cause environmental problems. This can be obtained in the mine itself or in the tailings when metal sulphides are exposed to surface and made contact with air and water. As the sulphides are oxidised, metal ions and sulphuric acid are released and with time as pH is decreasing the conditions becomes even more favourable for the bacteria. This phenomenon is called acid mine drainage (AMD) or acid rock drainage (ARD). It is for this reason that a very important action has to be taken to avoid environmental damages by these bioleaching microbes upon closure of a mine.

4. PRACTICAL BIOLEACHING

Bioleaching is mainly applied with heap leaching and stirred tank leaching technologies (Rawlings *et al*, 2003). Heap leaching involves extraction of metals from ores or rocks tailings that cannot be extracted by conventional methods, being placed on the bases that have low permeability and then being sprayed with solvent to extract the metal. Heap leaching is mainly applied on low grade Copper ores with 1–3% of Copper mainly as secondary Sulphide minerals as Covellite (CuS) and Chalcocites (Cu_2S).

In Bioleaching, these heaps are irrigated with raffinate, a waste water that typically contains 6 – 8 g/l of sulfuric acid (pH 1.8 – 2.2) and varying amount of ferric iron. The surface of the wet agglomerated ore provides an environment that supports the growth of a selection of iron and sulfur oxidizing bacteria and others that live in association with these microorganisms. The types of organisms present in the heap depend on the mineral being irrigated, as well as the temperature, acidity and degree of aeration of the heap.

Aeration is very essential for effective leaching. Aeration is passive when air drawn into the heap is as a result of liquid flow within the system; the leaching rate here is commonly limited by oxygen availability and factors such as bacterial population, particle size and built-in reaction rate have less significance.

Active aeration is when air is blown into the heap through pipes installed at the bottom; this technique secure adequate supply of oxygen to the greater part of the heap with increasing reaction rate as a result. This may significantly decrease the leaching time. But the costs are increases (Bartlett, 1997).

The depth of oxygen penetration into the heap depends on the physical properties such as the coarseness of the mineral, the rate of irrigation and whether aeration is passive or active.

Heap leach project can be developed on permanent bases; that is, the spent ore is left on the base after leaching, the base is acting as liner. Conversely, if the leached ore is disposed after the metal is extracted, the base can then be used again.

Metal recovery is achieved by solvent extraction followed by electrowinning (SX – EW). In the solvent extraction unit, the pregnant leach solution containing 1 – 5 g/l of copper is concentrated with organic solution containing an extractant, usually different forms of hydroxyoximes, that selectively extract copper ions into the organic phase. After phase separation, the copper is back extracted into an aqueous phase by contacting with spent electrolyte from the electro winning stage. The solvent extraction of copper is a cation exchange mechanism where extraction is favoured by low pH 1.5 – 2.0 and stripping is done at highly acidity, typically 200g/l of sulphuric acid according to the following general reaction formula.

$$2RH(org) + Cu^{2+}(aq) \longleftrightarrow R_2Cu(org) + 2H^{+}(aq)$$

The stripped aqueous phase is now concentrated to 40 – 45 g/L of copper and is transferred to the electrowinning plant where Copper is plated out on a cathode. The cathode starting sheet is usually a thin sheet made of stainless steel or pure copper while the anode consists of an insoluble alloyed lead sheet. The following reactions occur at the anode and cathode respectively (Backstrom, 2013) .

Anode: $2H_2O \longrightarrow O_2 + 4H^{+} + 4e^{/}$

Cathode: $Cu^{2+} + 2e^{/} \longrightarrow Cu^{o}$

Cell Reaction: $Cu^{2+} + 2H_2O \longrightarrow Cu^{o} + O_2 + 4H^{+}$

Typical operational data for electrowinning of Copper is a cell voltage of 2 – 2.5v, current density of 230A/m^2 and current efficiency of approximately 90%.

The different solutions in a process with heap leaching and SX – EW are recycled in close loops i.e raffinate from solvent extraction is recycled to the leaching and the acid spent electrolyte is used for stripping of the loaded organic phase in the solvent extraction circuit, as is illustrated in figure below.

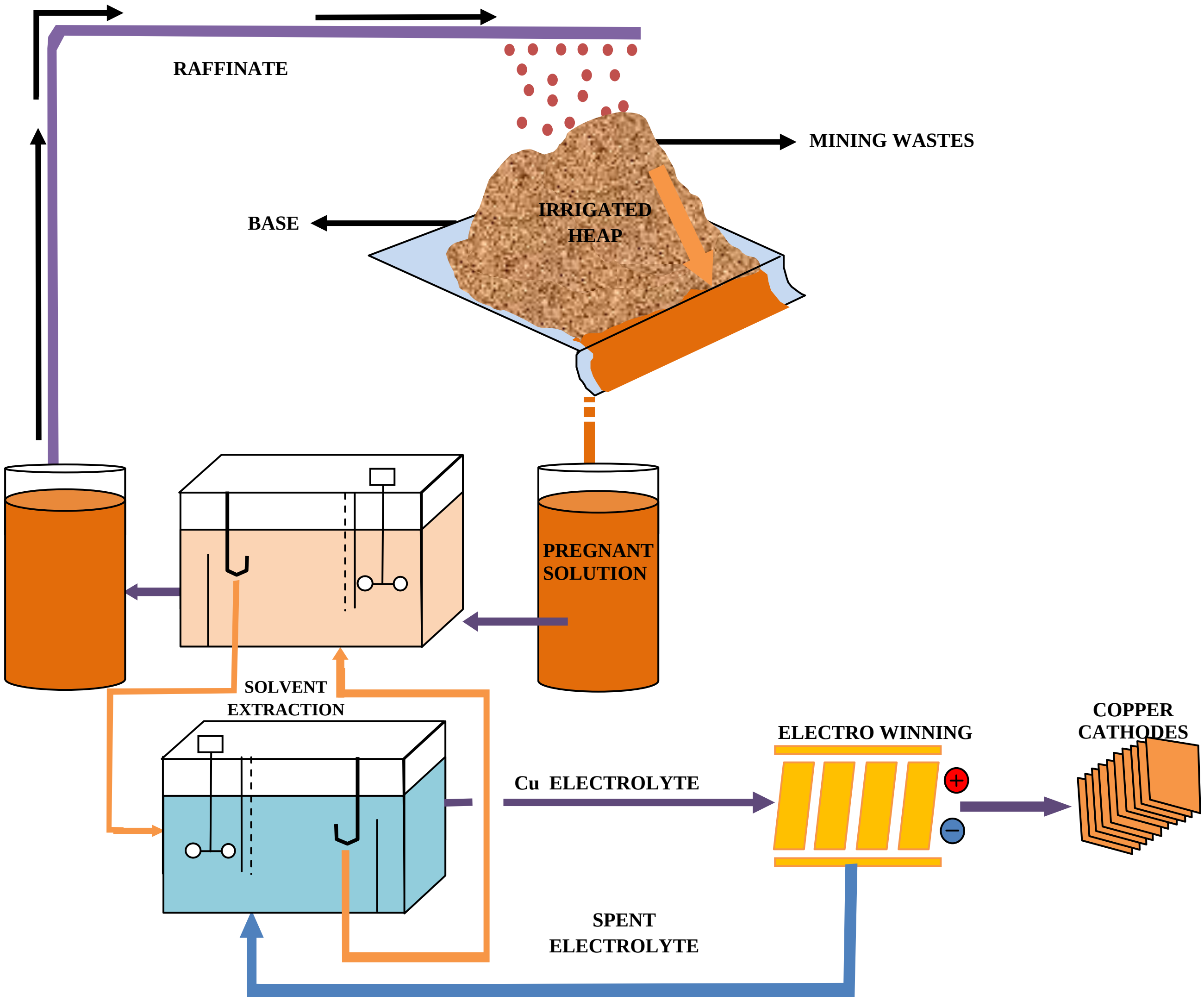

Fig. 1: Schematic Illustration of Copper Production through Bioleaching followed by SX – EW

Bioleaching can also be done by utilization of thermophilic microorganisms by increasing the temperatures. This is achieved by careful control of the aeration to maximize heat generated in the heaps through exothermic sulphide oxidation reactions and in some cases thermo fill of polyethylene sheets have been used to cover the heaps to reduce heat radiation losses. By operating at higher temperatures, higher leaching rates are obtained and thereby making it possible to treat hard ores such as chalcopyrite ores.

Table 2 Some Copper Bioleaching Companies in the World

Operation	Cu (Tons/Year)	Location
Cyprus Miami Mining Corp	73 000	Miami, AZ, USA
Cyprus Sierrita Corporation	21 800	Green Valley,AZ, USA
Burro Chief Copper Co-Phelps Dodge Tyrone	74 980	Tyrone, NM, USA
Burro Chief Copper Co-Phelps Dodge Chino Mines Co.	66 200	Santa Rita, NM, USA
Silver Bell Mining L.L.C.	21 000	Marana, AZ, USA
BHP Billiton Copper San Manuel	22 600	San Manuel, AZ, USA
BHP Billiton Copper Pinto Valley	6 800	Miami, AZ, USA
BHP Billiton Copper Miami	10 400	Miami, AZ, USA
Sociedad Minera Cerro Verde S.A	60 000	Arequipa, Peru
Cociedad Contractuel Minera El Abra	225 000	Region II (Calama), Chile
BHP Billiton Compania Minera Cerro Colorado	100 000	Mamina, Chile
Codelco Chile-Division Radimiro Tomic	180 000	Region II (Calama), Chile
Codelco Chile- Division El Teniente	4 800	Sewell Rancagua, Chile
Hellenic Copper Mines Ltd	5 000	Nicosia, Cyprus
Compania Minera Zaldivar	131 500	Region II, Chile
Girilambone Copper Co.	17 500	NSW, Australia
Mt Cuthbert Copper Co.	4 900	Queensland, Australia

Source: Rawlings *et al*. (2003) in Backstrom, (2013)

5. METALS RECOVERED IN BIOLEACHING PROCESSES

For many years Bioleaching was thought to be a technology for the recovery of metals from low-grade ores, but today is being used as main process for recovery of copper described above and as important pretreatment step for gold recovery in their respective mining processes (Sidiqui *et al* 2009)

5.1 Uranium Recovery

Uranium recovery proceeds in very similar way to copper recovery. Much like Copper, Uranium is recovered by the conversion of insoluble uranium oxides to soluble sulfates though the action of ferric iron and sulfuric acid produced by microbes.

$$UO_2 + Fe_2(SO_4)_3 \longrightarrow UO_2SO_4 + 2FeSO_4$$
$$UO_3 + H_2SO_4 \longrightarrow UO_2SO_4 + H_2O$$

Bacterial activity is limited to oxidation of pyrite and ferrous ion (McCready and Gould, 1990). Bioleaching has been successfully used to obtain uranium from waste gold ore.

5.2 Bioleaching of Other Metals

Metals which are present in an insoluble reduced sulfur form and which are turned in soluble when oxidized to a sulfate may be potentially recovered by Bioleaching. This includes minerals containing NiS and ZnS, Cobalt-containing Pyrite etc.

Lead is recovered from the pregnant Lead Acetate containing solution and the solution may subsequently be recycled to further leaching of Lead Sulfidic minerals or Lead Sulfide containing particles (Geisler and Punding, 1996). Although Bioleaching provides the possibility of recovering metals from many low-grade deposits that would otherwise be considered waste, its application greatly depends on the value of the metal to be recovered (Rawlings, 2002) and (Dew and Miller, 1997). A major challenge is to find a suitable match between an ore body and Bioleaching technology and to identify suitable concentration and size which allow economic recovery.

6. CONCLUSION

Bioleaching is a rather new technology that has been changing rapidly. It is being used worldwide to reclaim metals from abandoned old mine wastes and to also remove poisonous chemicals from old mine areas. Bioleaching can be thought as the acceleration of a natural environmental process using naturally occurring organisms that leach or separate sulphide minerals from ore. Though, the process is very slow, but proved to be economical and currently, companies are using bioleaching for the extraction of copper from low grade ores (Walter, 2011).

The future of bioleaching is challenging, as it offers advantages of operational simplicity, low capital and operating cost and shorter construction times that no other alternative process can provide. In addition, minimum environmental impact and the use of this technology in the mining industry is set to increase.

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