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Opportunities and Challenges in Bio Treatment of Industrial Waste Water

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ABSTRACT

Microorganisms have a tremendous influence on their environment through the transfer of energy, charge, and materials across a complex biotic mineral–solution interface. The bio-modification of mineral surfaces involves the complex action of microorganism on the mineral surface. The manner, in which bacteria affect the surface reactivity and the mechanism of adsorption and accumulation of the primary data in this area are only starting. Bio-Processing involves the selective removal of undesirable mineral constituents from an ore through microbe-mineral interactions in the processes such as selective flotation and flocculation. At the same time, bio-sorption has made a considerable progress in moving from theory to industrial practice as it is not only environmental useful but also more economical than many other processes. The bio-flotation, bio-flocculation and bio-sorption processes concern the mineral response to the bacterium presence, which is essentially interplay between microorganism and the physicochemical properties of the mineral surface, such as the atomic and electronic structures, the net charge/potential, the acid–base properties, and the wettability of the surface. The adhesion of microorganisms to minerals result in alteration of surface chemistry of minerals relevant to beneficiation process due to a consequence of the formation of a biofilm on the surface or bio-catalyzed surface oxidation or reduction products. There is an urgent need for developing basic knowledge that would underpin biotechnological innovations in the natural resource processing technologies that deliver competitive solutions.

1. Introduction

The new millennium rightly belongs to biotechnology, and rapid progress in minerals processing based on biological principles is just around the corner. The biological processes are becoming more attracting in mineral processing due to their lower operating costs and their possible applications to treat difficult to beneficiate low grade complex ores, **[1-3]**. Metal and energy extractive industries play a strategic role in the economic development of all countries. At the same time, these industries present the major threat to the environment. In fact, mining waste is one of the largest waste streams and is responsible for 18% of overall waste generation **[3]**. Oxidation of metal sulfides in mines, mine dumps, and tailings is a notorious source of acidity, heavy metals (e.g., Fe^{2+}, Mn^{2+}, Al^{3+}, Cu^{2+}, Pb^{2+}, Cd^{2+}, Zn^{2+}, etc.), and oxy-anions (CrO_4^{2-}, AsO_4^{3-}, etc.) contamination for streams and groundwater, which poses a serious threat of short- and long-term environmental degradation. Mining tailings can be additionally contaminated by chemical reagents—collectors, modifies, frothers, flocculants, etc. The use in mineral processing of substances potentially dangerous to the environment and/or human health was approx. 257.000 tons, which amounted to 1% of the total tonnage of material produced.

To protect public health and safety as well as the environment, the disposal, safety, recycling, and remediation of mining waste require very high costs on processing, containment monitoring, and diverting capital for development programs. These costs negatively impact market competitiveness of metal and energy extractive industries. To overcome the problem, the mineral industries have made large efforts to reduce overall costs through rationalizations of the conventional (chemical and physical) schemes of ore and ore waste processing, e.g., towards limiting the use of dangerous substances, decreasing waste streams and improving waste disposal and recycling practice. The most promising new approach based on integral green-chemistry methods is the biotechnological approach.

Two major areas, which are making advances in minerals bio-processing, are bio-leaching and bio-beneficiation. Bio-leaching can be defined as a hydrometallurgical dissolution process assisted by microorganisms for the recovery of metals from their ores/concentrates. Over the past three decades, bio-leaching has come a long way and is now economically competitive, many processes have been commercialized and are in use. Whereas, bio-beneficiation is relatively a new area and a new term that utilizes microorganisms as surface modifiers to enhance the separation of the mineral from another either by flotation or flocculation, **[4,5]**.

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Biological processes are attractive since microbes or microbial fat and secreted metabolites can have specific interactions with minerals. Such interactions of microbes and their agents with minerals can be indirect, with biological products acting as surface-active agents, or direct due to microbial adhesion or attachment to particles bringing out surface modification. Both types of interactions can lead to alteration of mineral hydrophobicity, and in some cases cause flocculation or dispersion of mineral suspension. The end result of such biological processes is the formation and conversion of various mineral forms as:

- Surface modification
- Selective dissolution of mineral constituents
- Bio-accumulation of dissolved metal ions
- Bio-environmental control
- Bio-medical engineering

Large-scale commercial applications of such bio-reagents include antisealants, dispersants, and fertilizers. Ceramics processing with biogenic additives has thus become possible. Bio-polymers can be used to control plasticity of clays, and colloidal stability of fine particles can be enhanced through biogenic additions. Microbes can also remove toxic metal ions from ground and surface-waste-water by bio-sorption or bio-accumulation processes **[7,8]**. Dispersion or flocculation of ceramics and mineral particles can be achieved through biological treatment. The bio-reagents used are the microbial cultures, microbial cells and microbial metabolites (aqueous environment in which microbes grow). It is imperative to develop novel economically more efficient and environmentally benign methods of waste processing, exploiting the intriguing and exciting ability of bacteria to selectively modify the surface properties of solids. The bio-modification of mineral surfaces involves the complex action of microorganism on the mineral surface. There are three different mechanisms by means of which the bio-modification can occur:

1. Attachment of microbial cells to the solid substrate.
2. Oxidation reactions.
3. Adsorption and/or chemical reaction with the metabolite products.

2. Microorganism's Definition

Microorganisms represent a large and diverse group of different organisms that exist either as single cells or cell clusters. A single microbial cell is generally able to carry out its life processes of growth, energy generation, and reproduction independently of other cells, either of the same kind or of different kinds. Microorganisms may be classified as bacteria, fungi, algae, or viruses.

3. Classification of Bacteria

Most Bacteria and Archaea are between 500 nanometers (nm) and 2 micrometers (μm) in diameter, with a volume between 1 and 3 μm and a wet weight approximating 10^{-12} grams. The only way to observe such small objects is by microscope, hence the term microorganisms or microbes. Individual cells most frequently occur as rods (known as bacilli), spheres (known as cocci), or helical shapes (known as either spirilla or vibrio), Fig. 1. These different shapes in turn affect the relationship between volume and surface area: rods have a surface area to volume ratio of 10:1; spheres 5.8:1; and helical-shaped, 16:1, [9]. Individual cells also commonly form together in groups or clusters after division. When they grow end on end, they form what are known as filaments.

Also, as seen in Fig. 2, any bacterial cell consists of capsule, cell wall, plasma membrane, S-layer, Fimbrae and bacterial flagellum.

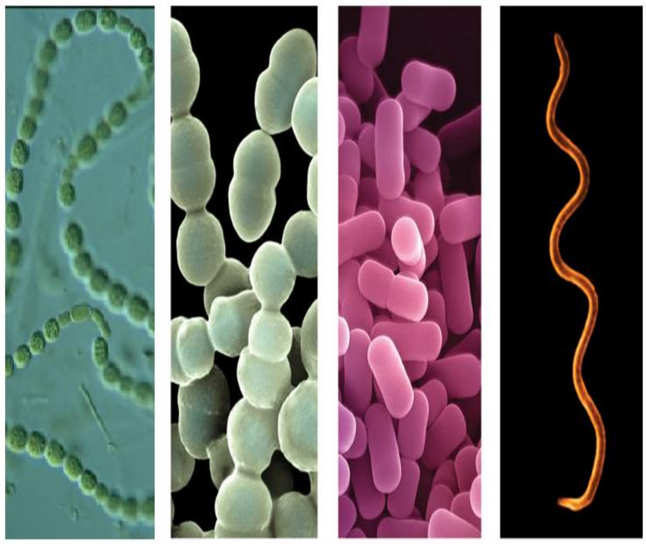

Fig 1. Basic shapes of bacteria as seen under the scanning electron microscope (SEM). (A) Filaments, (B) Spherical, Cocci, (C) Rod, Bacilli (D) Spiral.

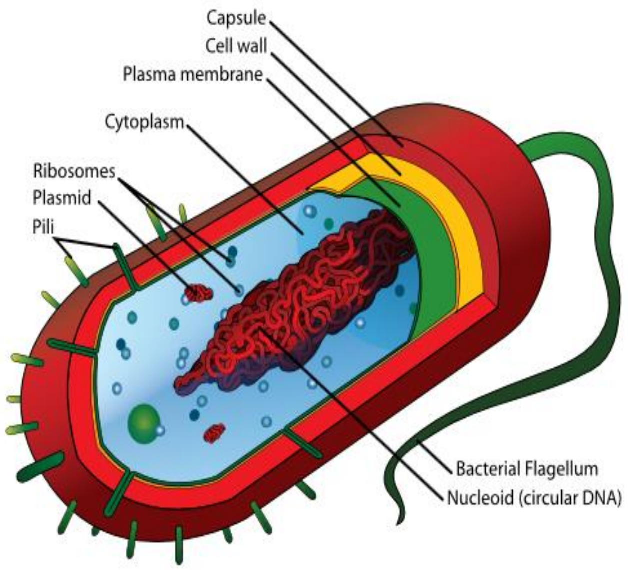

Fig 2. Extracellular structure of bacteria.

4. Bacterial Cell Composition

Microorganisms have a variety of surface enveloping layers, including the cell wall and extracellular structures residing above them that are directly exposed to diffusible components in the external aqueous environment. Historically Gram staining method was an important step towards the identification and characterization of bacteria to Gram-positive and Gram-negative. The Gram-positive and Gram-negative bacterial cell surface structures are presented in Fig. 3. Gram-positive bacteria surface is composed mainly of peptidoglycan, linked together by a peptide interbridge. Many Gram-positive bacteria are having several sheets of peptidoglycan creating a thick layer. Usually 90% of the outer membrane is peptidoglycan, while the rest is teichoic acid and some wall-associated proteins. Gram-negative bacteria, in addition to a peptidoglycan, have a second lipid bilayer. This layer contains lipids and polysaccharides linked together, creating a lipopolysaccharide layer.

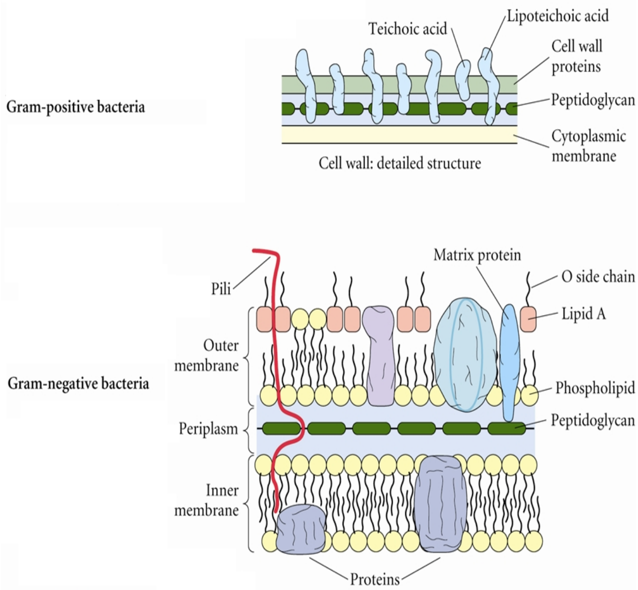

Fig. 3. Bacterial cell surface [10,11]

Regardless of the cell's surface composition, microorganisms often produce some additional surface layers called extracellular polymeric substances (EPS). The need of large scale bacterial mass with associated secretion products to fully cover and alter the surface properties could be the reason for using certain types of microorganisms that are more capable to produce secretion products. Metabolic products secreted by some organisms are shown in Table1. The amount of EPS and surface properties could be influenced by the growth conditions, **[12]**.

Table 1. Metabolic products secreted by some microorganisms.

Microorganisms	Major Metabolic Products
Pseudomonas sp.	Citric, oxalic and gluconic acids
Bacillus Polymyxa	Acetic acid
Bacillus Circulans	Succinic, formic, fumaric and maleic acids
B. mucilaginosus	Exopolysaccharides
Thiobacillus sp.	Sulfuric acid, proteins
Aspergillus niger	Citric, oxalic and gluconic acids
Penicillium sp.	Citric and oxalic acids
Bacillus sp.	Amino acids

5. Bio-Film Formation

A bio-film is a matrix of cells and cellular products attached to a solid surface or substratum. Bio-films can present a problem when they occur in unwanted locations such as industrial process equipment or implanted medical devices. But these microbial films can also present positive opportunities in bioremediation of hazardous and toxic substances in ground and surface water and wastewater treatment. Bio-film and other immobilized cell reactors offer significant advantages in bio-processing. Engineers and scientists are just beginning to realize the significance of bio-films on process industries, natural aquatic systems, and medical technology. Intricate knowledge of microbiology, chemistry, and engineering must be combined to fully understand the processes affecting bio-film accumulation and activity. Bio-films typically accumulate on surfaces exposed to flowing water. The accumulation of a microbial film is most likely rate-limited by the transport of nutrients to and by-products from the bulk liquid to the bio-film. Cellular attachment to a solid surface provides a suitable environment for many types of microorganisms under varied and sometimes harsh conditions, **[13].** The progression of bio-film accumulation typically follows a sigmoidal-shaped curve in terms of bio-film mass, cell numbers, or thickness, Fig. 4.

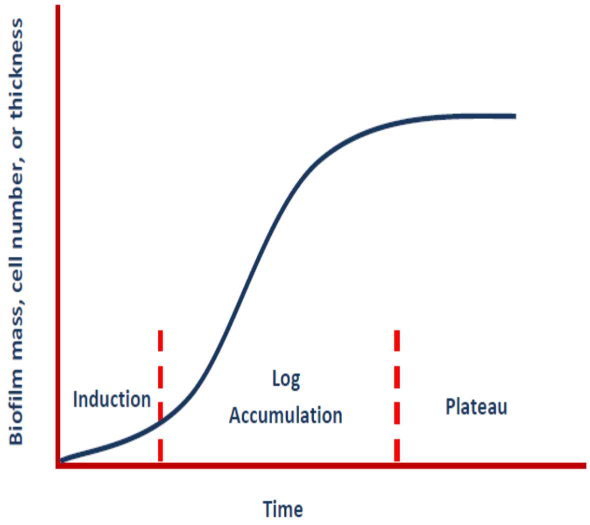

Fig 4. Characteristic S curve of bio-film accumulation with time.

Bio-film accumulation is the net result of various processes that can be identified and quantified as follows, Fig. 5:

1. **Adsorption:** The interphase accumulation of cells from the bulk liquid directly on the substratum.
2. **Desorption:** The re-entrainment into the bulk fluid of a cell adsorbed to the substratum.
3. **Attachment:** The acquisition of cells from the bulk liquid by an existing bio-film.
4. **Detachment:** The re-entrainment into the bulk fluid of cells from an existing bio-film.
5. **Growth**: The increase in the number of bio-film cells as a result of replication.
6. **Product Formation:** The production of polymers and metabolic byproducts in the bio-film.
7. **Endogenous decay:** Bio-film cell metabolism of internal cellular materials.
8. **Death:** Permanent loss of a cell's reproductive and metabolic activity.

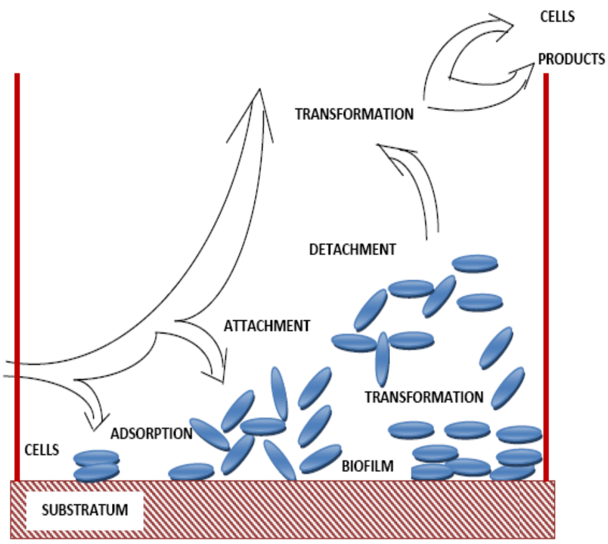

Fig 5. Schematic illustration of the processes contributing to bio-film accumulation and activity.

6. Application of Microorganisms in Enviroment Protection

i. Bio-Sorption

Comprising over 70% of the Earth's surface, water is undeniably the most valuable natural resource existing on our planet. Without this invaluable compound, the life on the Earth would be non-existent. Although this fact is widely recognized, pollution of water resources is a common occurrence. In particular, potable water has become greatly affected, and in many instances has lost its original purpose. There are many sources of water pollution, but two main general categories exist: direct and indirect contaminant sources. Direct sources include effluent outfalls from industries, refineries and waste treatment plants; whereas, indirect sources include contaminants that enter the water supply from soils/ground water systems and from the atmosphere via rain water. In general, contaminants come under two broad classes, viz. organic and inorganic. Some organic water pollutants include industrial solvents, volatile organic compounds, insecticides, pesticides and food processing wastes, etc. Inorganic water pollutants include metals, fertilizers and acidity caused by industrial discharges, etc. Metals are extensively used in several industries, including mining, metallurgical, electronic, electroplating and metal finishing. The presence of metal ions in final industrial effluents is extremely undesirable, as they are toxic to both lower and higher organisms. Under certain environmental conditions, metals may accumulate to toxic levels and cause ecological damage. Of the important metals, mercury, lead, cadmium and chromium (VI) are regarded as toxic; whereas, others, such as copper, nickel, cobalt and zinc are not as toxic, but their extensive usage and increasing levels in the environment are of serious concerns. Radionuclides, such as uranium, possess high toxicity and radioactivity, and exhibit a serious threat, even at small concentrations. In most developed and developing countries, stricter environmental regulations, with regard to contaminants discharged from industrial operations, are being introduced. This means that industries need to develop on-site or in-plant facilities to their own effluents and minimize the contaminant concentrations to acceptable limits prior to their discharge. Various techniques have been employed for the treatment of dye/metal bearing industrial effluents, which usually come under two broad divisions: abiotic and biotic methods. Abiotic methods include precipitation, adsorption, ion exchange, membrane and electrochemical technologies. Much has been discussed about their downside aspects in recent years, **[14]**, which can be summarized as expensive, not environment friendly and usually dependent on the concentration of the waste. Therefore, the search for efficient, eco-friendly and cost effective remedies for wastewater treatment has been initiated.

In recent years, research attention has been focused on biological methods for the treatment of effluents, some of which are in the process of commercialization. There are three principle advantages of biological technologies for the removal of pollutants:

1. Biological processes can be carried out in situ at the contaminated site
2. Bio-process technologies are usually environmentally benign (no secondary pollution)
3. They are cost effective.

Bio-sorption can be defined as the passive uptake of toxicants by dead/inactive biological materials or by materials derived from biological sources. Bio-sorption is due to a number of metabolism-independent processes that essentially take place in the cell wall, where the mechanisms responsible for the pollutant uptake will differ according to the bio-mass type. Bio-sorbents for the removal of metals/dyes mainly come under the categories of bacteria, fungi, algae, industrial wastes, agricultural wastes and other polysaccharide materials. In general, all types of bio-materials have shown good bio-sorption capacities towards all types of metal ions. A summary of bio-sorption results reported in literature is presented in Table 2.

Table 2. Summary of bio-sorption results in literature.

Metal	Organism
Aluminum	Chryseomonas luteola, [14]
Chromium (VI)	Staphylococcus xylosus, [15]
Copper	Bacillus sp. (ATS-1), [16] Pseudomonas putida, [17]
Cadmium	Aeromonas caviae, [18] Bacillus circulans, [19]
Iron (III)	Streptomyces rimosus, [20]
Lead	Pseudomonas aeruginosa, [21]
Mercury	Bacillus sp., [22]
Nickel	Bacillus thuringiensis, [23]
Palladium	Desulfovibrio desulfuricans, [24]
Platinum	Desulfovibrio fructosivorans, [25]
Thorium & Uranium	Bacillus subtilis [26] Corynebacterium equi Micrococcus luteus Nocardia erythropolis Zoogloea ramigera,
Zinc	Pseudomonas putida, [27]

7. Conclusions

• There is, thus, a great need for extensive applied research work exploring the fundamentals, potentials and practicality of the various potential uses of microorganisms in mineral processing**.**

• Though the mechanisms of adsorption of the microbe’s extracellular polymeric substance (EPS) components onto solid surfaces are generally known, they are system specific **.**

• There is a need to study the mechanisms of the interaction of each of bacterial cells and their metabolic products grown in the presence of different culture media and specific minerals as well as their interaction with mineral surfaces and added surfactants or chemicals**.**

• However, except for some mechanisms, practical exploitation of the bio-technological potential of most of the above bioprocesses needs more feasibility studies **.**

• There have been several attempts to commercialize bio-sorption using microbial bio-mass with a promising success. As a result, knowledge-based control, optimization, and design of the biotic interfaces are still considered as a matter of the future.

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