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Microbial leaching in environmental clean-up programmes

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Abstract

Microbial leaching is a simple and effective technology for extracting valuable metals from low-grade ores and mineral concentrates. Besides the industrial application for raw materials supply, microbial leaching has some potential for remediation of mining sites, treatment of mineral industrial waste products, detoxification of sewage sludge and for remediation of soils and sediments contaminated with heavy metals. There is no routine treatment for toxic metals dispersed in solid materials, and autotrophic and heterotrophic leaching processes may be considered for environmental clean-up programmes. The problems of bioremediation for heavy metal-contaminated sites are very different from those of bioremediation for organic pollution, but intensive interdisciplinary collaboration in basic and applied research in this economically important field is expected to be very beneficial in the near future. It would be ideal if the bioremediation system maximised the extent and rate of degradation of waste materials, simultaneously minimising the level of toxic substances during the operation.

Keywords: Microbial leaching; Bioremediation; Waste; Soils; Sediments

1. Introduction

As a consequence of technological and industrial development, many industrial sites are contaminated with heavy metals and/or organic compounds. The main problem of this kind of anthropogenic waste is that it is toxic to organisms of any kind and particularly to human beings. Therefore, it is important to remove or minimise these metal and organic contaminants to minimise the danger to health when consuming food and breathing the air and to prevent contaminants being dissolved and distributed by surface and groundwater.

Organic contaminants may be degraded biologically and CO_2 and water are the final products [1–3]. In contrast to organic compounds, heavy metals cannot be decomposed, either biologically, chemically or physically. Metals may be solubilised, they may be changed in valence or in chelating state, they may be immobilised, but they are still metals. At low concentrations, many metals are essential parts of metabolic processes but at high concentrations, they are toxic and careful clean-up programmes are necessary to save our environment.

Microbial leaching is a simple and effective technology used for metal extraction from low-grade ores and mineral concentrates [4–6]. Metal recovery from sulphide minerals is based on the activity of chemolithotrophic bacteria, mainly *Thiobacillus ferrooxidans*, *Thiobacillus thiooxidans* and *Leptospiril-*

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lum ferrooxidans, which convert insoluble metal sulphides into soluble metal sulphates. Non-sulphide ores and minerals can be treated by heterotrophic bacteria and fungi. In these cases, metal extraction is due to the production of organic acids and chelating and complexing compounds excreted into the environment. In addition, metals may be solubilised or immobilised by chemical or biochemical changes in oxidation states. Besides the industrial application for the raw materials supply, microbial leaching has some potential for the environmental clean-up of mining sites, treatment of mineral industrial waste products, detoxification of sewage sludge and for remediation of soils and sediments contaminated with heavy metals.

As reported by Summers [7], the basic problem of metal bioremediation is "... the occurrence of metals in soil, rock or sediment, or in water, at concentrations too dilute to be worth mining (if the metals are valuable) or sufficiently concentrated to be an environmental concern (if the metals are toxic). The process employed for metals that are more valuable than toxic is called biorecovery and the hope of cheaper and more efficient strategies for their enrichment and re-use is the driving force for interest in this area. For metals that are toxic but not intrinsically valuable, the processes are referred to as bioremediation and the driving forces are increasingly strict standards for water and air quality."

2. Bioremediaton feasibility

2.1. Mining sites

Intensive mining and ore processing have produced billions of tonnes of waste all over the world, a continuing process. Depending on the mineral composition of the mine tailings and waste rocks, and affected by the environmental geological and climatic conditions, mining sites represent a serious hazard to the environment. Tailings containing heavy metal sulphides are oxidised by weathering processes accelerated by naturally occurring sulphur and iron-oxidising bacteria, and the dissolved metals will contaminate ground and surface waters. This phenomenon is recognised world wide as acid mine or acid rock drainage (AMD/ARD) and several technologies have been developed for the treatment of the acid and metal containing mine waters. Treating the mine water however, does not mean removing the root of all evil. For this reason, techniques for deactivating the pollution source and inhibition of metal dissolution are developed (neutralisation, revegetation). On the other hand, heavy metal-contaminated mine sites can be remediated by using adapted, sophisticated heap and dump leaching technologies where optimum conditions for the growth of the leaching microorganisms are kept constant and any seepage of the leachate is prevented. In this way, both processes, remediation of mining sites and recovery of valuable metals, may be achieved simultaneously [8].

2.2. Mineral industrial waste materials

Mineral industrial waste products (fly ash, slag, incineration cinders) often contain substantial amounts of toxic metals, which in the case of inadequate disposal may be mobilised and may cause hazardous environmental problems if they reach the soil or the groundwater. Meanwhile, special waste disposal sites exist and special waste-treatment plants have been established in several countries. Very often, waste disposal is subject to strong governmental restrictions. Therefore the costs of waste removal continuously increase, and environmental protection laws may create economic problems.

In the case of industrial mineral residues, conventional bioleaching may fail, since most metals are present mainly as oxides rather than as sulphides. Metal oxides in such residues can be leached by microbial acid production, e.g. sulphuric acid generated by *T. thiooxidans*. In some cases, chemical acid leaching is easier. Bioleaching with *T. thiooxidans* may be advantageous, when in chemical leaching, high costs would arise for the transport of the acid and on the other hand, sufficient sulphur for bacterial acid production is cheaply available. Another advantage is that as a consequence of sulphuric acid production during the growth of *T. thiooxidans*, the pH in the leach suspension falls only gradually so that the metals pass into solution at different rates corresponding to their solubilities, and can be separated from the leaching suspension selectively. Residues containing metal carbonates and silicates may be remediated by organic acids produced by heterotrophic bacteria and fungi. In these cases, one of the main problems is in searching for cheap organic substrates necessary for the growth of heterotrophic microorganisms [9–11].

2.3. Sewage sludge

Sewage sludge has been used as fertiliser on farmland for a long time. But with the realisation that sewage sludge might be seriously contaminated by toxic metals, this common practice of waste management has become no longer acceptable or has even been banned. Since the work of Tyagi and Couillard [12] and Couillard and Zhu [13], who isolated chemolithotrophic thiobacilli tolerant to organic compounds, previous detoxification of sewage sludge by bioleaching seems to be a practicable alternative. In the meantime, an appropriate technology is being developed [14].

2.4. Aquatic sediments

Disposal of sediments from rivers and docks causes major environmental problems because most sludge contains high amounts of toxic metals. When exposed to air, due to oxidation processes, the sludge turns acid and heavy metals are mobilised. At present remediation techniques are being developed based on accelerating naturally occurring bioleaching by activating the autochthonic thiobacilli. The addition of elemental sulphur increases acidification, followed by an increase in metal extraction [15–17].

2.5. Soils

Because the most important metal leaching bacteria (*T. ferrooxidans* and *T. thiooxidans*) have been found to be sensitive to even low concentrations of organic substances [18] only a few efforts have been made to apply bioleaching techniques to remediation of contaminated soils. In preliminary studies, we were able to show that metals mobilising bacteria could be isolated from various heavy metal-contaminated soils. The enrichment cultures solubilised toxic metals to various extents, depending on the enrichment medium, the soil sample, and the type of contaminant. In some cases, the heavy metal contamination was reduced to such an extent that threshold values were reached, recommended for almost unrestricted use of the soil [8,19].

2.6. Radioactive waste

Radionuclides are present in soils, ores and residues mainly as oxides, usually in crystalline form, insoluble and often co-precipitated with iron oxides. Direct dissolution is possible by enzymatic reduction from higher to lower oxidation state, indirect mobilisation occurs via solubilisation by microbial metabolites such as organic acids and chelating agents. Uranium contaminated soil was successfully remediated by bacterial leaching with *T. ferrooxidans* and at a laboratory scale 99% of uranium was extracted within 17 days [20–22].

3. Conclusions

Bioleaching has serious potential for remediation of heavy metals contaminated materials. There is no routine treatment and leaching processes using autothrophic or heterotrophic microorganisms may be considered for environmental clean up. As with other bio-hydrometallurgical techniques, remediation by bioleaching is of great economic advantage because biohydrometallurgical processes are low in capital and energy costs, they show high flexibility, they may be used on site and do not cause environmental pollution. As a rule of thumb, bioprocesses are one-third to one-half the cost of conventional chemical and physical remediation technologies [8]. Although the problems of bioremediation for heavy metal-contaminated sites are very different from those with organic pollution, intensive inter-disciplinary collaborations in basic and applied research will be very beneficial in the near future [7]. Genetic improvement of metal solubilising microorganisms, whether by mutation and selection or by genetic engineering, will allow the bioremediation processes to be improved. It would be ideal if the bioremediation system yielded maximum degradation of waste materials and minimised the hazardous risk potential at the same time [8].

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