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Biological Opportunity for Beneficiation of Low-grade Bauxite

Archana Pattanaik, Lala Behari Sukla*, Debabrata Pradhan*,
Biofuels and Bioprocessing Research Center, Institute of Technical Education and Research,
Siksha 'O' Anusandhan (Deemed to be University), Bhubaneswar-751030, Odisha, India

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Abstract: The ore that contains <50 % of Al_2O_3 is called low-grade bauxite. It is suitably used for the production of the low-valued refractory materials and abrasives. The scope of its valuable use is curtailed due to the presence of different impurities like alumina-ferrite and alumina-silica. It cannot be used directly as Bayer's process feed as its high ferrite and silica content reduce the binding energy among the alumina grains, which eventually leads to a decline in the mechanical and physical properties of different aluminum utilities. However, it would be a suitable Bayer's process feed if the impurities can be removed in a low-cost and eco-friendly way. In this context, the conventional metal beneficiation techniques like gravity or magnetic separation, froth floatation, and reduction roasting can be applied; however, they require the huge plant set up, large amount of chemicals, and high energy input which together elevate the beneficiation cost and is of course not an eco-friendly way. Application of biomaterials in the metal beneficiation technique, especially for the removal of different impurities from the low-grade bauxite, is a suitable alternative to overcome the issues related to the process cost as well as environmental risks in the conventional beneficiation. This review article summarizes the suitability of bio-beneficiation for the low-grade bauxite.

Keywords: Bauxite; Impurity removal; Microorganism; Beneficiation mechanism.

Introduction

The bauxite ore containing less than 50 % of Al_2O_3 is classified as low-grade bauxite ore. The major impurities present in the low-grade bauxite ore are silica, iron oxides, and calcium. The presence of these impurities in a high percentage limits its utilities in different industries. The amount of calcium present in low-grade bauxite should be less than 0.5 % for its utilization in abrasive production [1]. Likewise hematite (Fe_2O_3) content should be less than 1% in it for its refractory applications. Therefore, the selective removal of these impurities is required to improve its economic value as well as industrial utilization. Although there are several physicochemical methods of impurity removal from bauxite but several disadvantages are associated with these methods, like high cost and energy consumption, less flexibility, and environmental problem [2-5]. Hence, an increasing effort is being devoted to search for alternative methods for beneficiation of bauxite. A better and more convincing solution to the above problem is to take up a biotechnological approach. These phenomena are eco-friendly and cost-effective, simultaneously doesn't require much technical expertise. Biological methods of beneficiation provide several advantages over conventional approaches [6-7].

There is a huge low-grade bauxite ore deposit in India. Upon utilization, it would give the new horizon to the Indian economy. Therefore, exploration in the biotechnological field for the bauxite purification should be emphasized by the government and different research institutes to accelerate the Indian economy.

*Corresponding author (Lala Behari Sukla, Debabrata Pradha)
E-mail: < suklalb@yahoo.co.in; dpradhanmetal@gmail.com >

Types of bauxite ore

Aluminum occupies the second most abundant metal in the earth crust next to silica and the major source of aluminum is bauxite. However only 8% of aluminum is present as metallic element in earth's crust and rest is present in the clay, soil, and rocks which cannot be extracted. Bauxite is the only ore to be used in the production of aluminum in the industrial scale. It is a heterogeneous ore that occurs by natural processes. It is composed mainly of aluminous oxide minerals (gibbsite ($Al_2O_3.3H_2O$), trihydrate, bohemite, diaspore ($Al_2O_3.H_2O$), and monohydrates, etc.), iron oxide (goethite & haematite), silica mineral (Kaolinite) & anatue TiO_2 in traces. The commercial type of bauxite contains gibbsite and boehmite in large amount, and is rich in aluminum oxide (40-60 %), iron oxide as Fe_2O_3 (7-30 %), silica (1-15 %), TiO_2 (3-4 %) and trace elements [8-9]. The majority of bauxite (80 %) produced worldwide is being utilized in the production of alumina by Bayer's process.

Mostly there are two major types of bauxite such as lateritic and karst. Both of them are formed by weathering of parent rock, i.e. aluminosilicate rocks and interbedded carbonate. The lateritic bauxite is composed of gibbsite as aluminous mineral, kaolinite as silicate mineral, and goethite iron mineral. It is formed by leaching of silica from aluminosilicate rock. Lateritic bauxite is classified into six major types based on conditions of weathering and deposit age [10-11]. The karst bauxite is composed of boehmite and diaspore as aluminous mineral and kaolinite as silicate mineral. The karst bauxite is widely distributed in Northern Asia and Eastern Europe. The differences in the composition of both bauxites are the result of different weathering conditions [12]. This composition differences influence their processing methods. The lateritic bauxite is easily digested compared to the karst bauxite in the Bayer's process.

Bauxite Reserves in Indian

Bauxite reserves of India are the 5th largest in the world. It has a wide distribution throughout the country with Odisha leading the list. Odisha accounts for the highest bauxite resources (53%) followed by Andhra Pradesh (16%), Gujarat (8%), Jharkhand (5%), Madhya Pradesh, Maharashtra and Chhattisgarh with 4% concentration each [13]. The majority of bauxite deposits are concentrated in the eastern coast of Odisha. More than 95% of bauxite deposits are accounted from the southern and western district (Koraput, Raygada, Bolangir and Kalahandi) of state [1].

Bio-beneficiation

The removal of unwanted minerals from ore using microorganisms for the enhancement desire mineral content in the ore is referred to as bio-beneficiation [14-17]. The beneficiation process mostly involves two steps such as comminution and concentration [18]. The traditional methods of mineral beneficiation are energy-intensive, costly and possess environmental concern [2]. Bio-beneficiation is considered as a promising solution to this problem as it is an environmentally friendly and economically viable process. The processes involved in microbial beneficiation of minerals are flocculation, flotation, and selective leaching [4,19]. Utilization of microbes in commercial extraction of some metals such as gold, uranium, copper, etc. is well established. A very little attention is devoted to the utilization of microorganisms for mineral beneficiation. The microbial beneficiation process has been described in the beneficiation of complex multi-metal sulfides, limestone, iron ores, and bauxite. Some laboratory experiments reported that microorganisms could play a similar role as that of conventional reagents in mineral beneficiation [20,21]. The major impurities present in bauxite are silicon, iron oxides, and calcium [19,22] which causes many processing problems affecting its utilization in ceramics, abrasives, and refractories. The presence of microorganisms in the natural environment of bauxite deposits is evidenced to bring about various biochemical reactions like reduction and dissolution of iron oxides, dissolution and precipitation of calcium and leaching of silica. These evidences give the possibility of using the microbes present in bauxite mines to selectively remove the impurities. Groudev *et al.*,[23] have proposed a flowsheet for microbial leaching of aluminum from mineral raw materials as shown in Fig. 1.

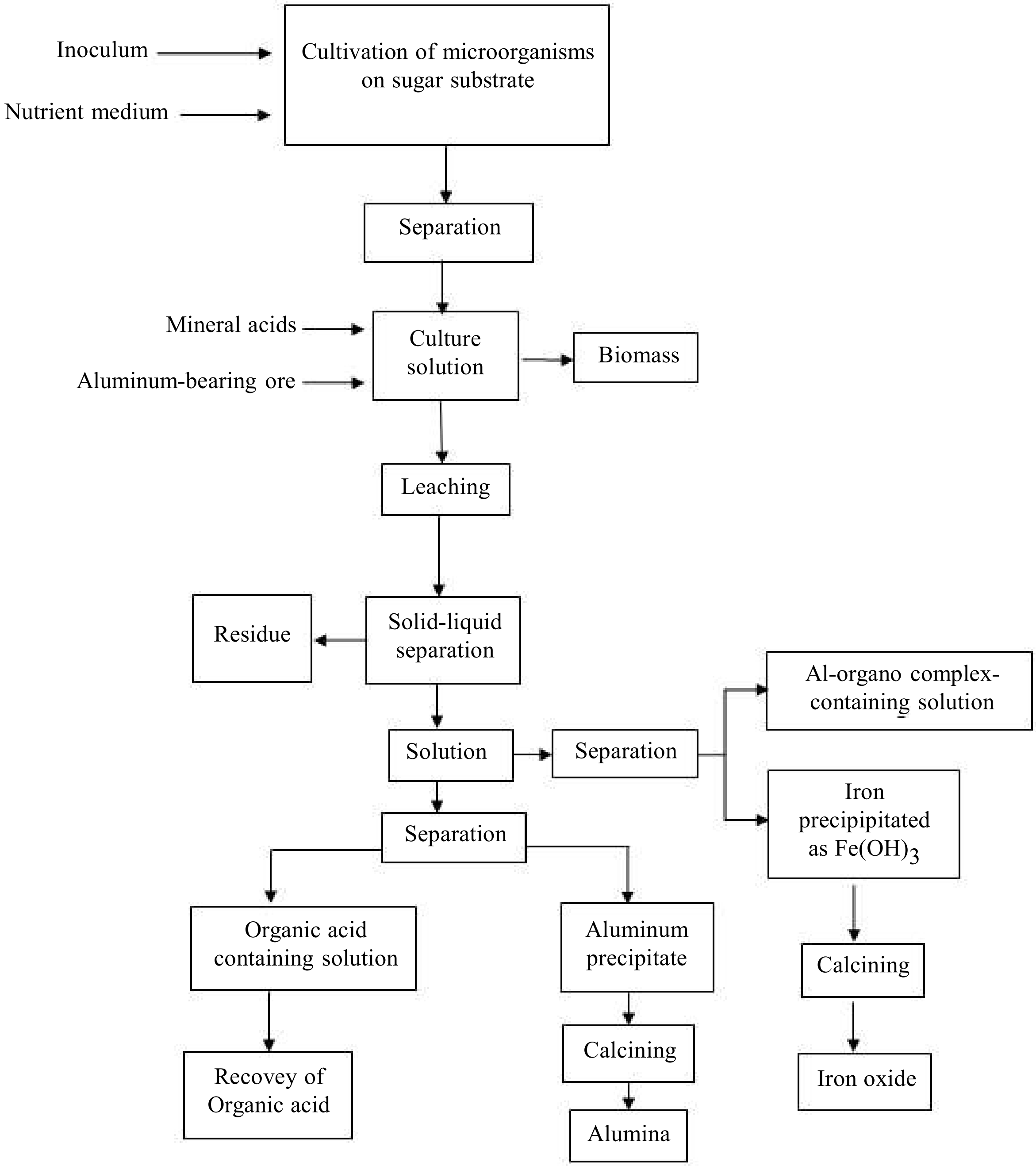

Figure 1. Flowsheet for microbial leaching of aluminum from mineral raw material [23].

Microorganisms involved in Bio-beneficiation

Both heterotrophic and autotrophic bacteria and some fungi are involved in metal removal from different ores [24,25]. The detailed study of the role of only a few bacteria (*Acidithiobacillus ferrooxidans, Acidithiobacillus thiooxidans, Desulfovibrio,* and *Paenibacillus polymyxa)* in mineral beneficiation have been carried out [19,26]. Chemolithotrophic microorganisms are the first choice of several researchers for the bio-beneficiation process as they use inorganic compounds or minerals of the ore as the source of energy. However, the strains of *Acidithio bacillus*, are mostly being used due to their capability in oxidizing sulfur and ferrous compounds [21,27]. Various laboratory experiments make use of heterotrophic microbes for beneficiation of ores [24,28].

Krishna e*t al.*[29] investigated the diversity of cultivable and non-cultivable bacteria in red mud using 16s rDNA sequencing method. The study identified the cultivable bacteria such as *Bacillus litoralis, B. anthracis, Agromyces indicus, Chungangia koreensis, K. polaris, Kokuria flava, Microbacterium hominis, Pseudomonas alcaliphila, Salinococcus roseus,* and *Planococcus plakortidis*. And the non-cultivable bacteria were affiliated to phyla bacterodidetes, betaproteobacteria and gammaproteobacteria [6]. These isolated bacteria are alkali tolerant, organic acid producers, and able to oxidize different carbon substrates.

Bahira *et al.*[25] studied aluminum leaching potential of the native bacteria isolated from the ore as well as the optimum conditions required for the process. The results show that the microorganisms isolated from the ore were gram -ve, motile, and rod-shaped bacteria with the ability to remove aluminum from the same ore. The study also reported that maximum aluminum leaching occurs at pH 9.22 in 0.3 gm of carbon source.

Microbial mechanism of bauxite bio-beneficiation

Microbial interaction with ore results in selective extraction or dissolution of different metals by the means of following mechanisms [21]:

a) Adherence of microbes on the ore matrix.

b) Surface modification by the microbial activities.

c) Biochemical reaction with the metabolic products produced during the microbial metabolism.

Both direct and indirect mechanisms are involved in bauxite beneficiation process. In the direct mechanism, microbial cells get attached to the ore surface resulting in surface modification of ore. Exo-polysaccharides (EPS) has a key role in the attachment of microbes to the mineral surface and selective dissolution of metals. Production of organic acids by microorganisms brings about selective removal of metals [17,30]. Iron and calcium can be removed from bauxite by chelating activity of organic acids produced by microbes involved in the beneficiation process. The extracellular polysaccharides present on the microbial cell surface also have a role in metal chelation [3,1,32]. According to Ehrlich *et al.*[33] and Friedrich *et al.*[34], there are three types of mechanisms involved in microbial interaction with the silicates, such as the destruction of silicate lattice, dissolution of silicon by bacterial metabolism, and removal of silicon by acidolysis. The dissolution of silicate is associated with the activities of metabolic products produced by the microbes which may break the Si-O bond or act as the chelating agent [35,36].

Bauxite bio-beneficiation

The bacteria *Bacillus polymyxa* is known to play an important role in the removal of impurities like calcium and iron from low-grade bauxite [31]. It is a chemoorganotrophic, facultative anaerobe which produces various metabolites like lactic acid, formic acid, acetic acid, succinic acid, ethanol, etc.[37-40]. The capsule of *Bacillus polymyxa* is formed by the extra-cellular polysaccharides (ECP) which is produced by its metabolism and acts as an effective chelating agent for iron-like metals [31,41,42]. Organic acids (acetic acid and lactic acid) are produced by fermentation under oxygen limiting conditions. Furthermore, *Bacillus polymyxa* facilitates the dissolution of iron by reducing ferric iron to ferrous. Calcium is required by *B. polymyxa* for its metabolism such as the production of enzymes, slime, and Ca-dipicolinate [37,43]. Thus it makes use of the calcium present in the ore to fulfill the requirement. Metabolites produced by the bacteria (polysaccharides, organic acids, etc.) play a significant role in removing calcium and iron from bauxite and the removal was found to be 50 % of that obtained in presence of bacteria [31]. As per the recent changes, *B. polymyxa* is referred to as *Paenibacillus polymyxa* [44]. Investigation on calcium removal through the cascade model of column bioleaching shows efficient removal of calcium (> 90 %) [45,46]. Using iron-reducing bacteria shows effective results in the removal of iron impurities from bauxite [47]. Several fungal species are known to produce organic acids which accounts for the reduction of iron. Papassiopi *et al.*,[48] studied the effect of organic acids (oxalic and citric acid) produced by the metabolism of *Aspergillus niger* on the removal of iron oxides from bauxite ore.

In this study, oxalic and citric acids were produced by fermentation of a medium composed of sucrose by fungus *Aspergillus niger*. The leaching capacities of these fungal produced organic acids were examined on bauxite sample which contained 16 - 19% of iron. The process of leaching using fungal produced organic acids as a leaching solution results in the removal of 80% of total iron from bauxite [48]. Papassiopi *et al.*,[49] investigated the combined effect of ethylene-diamine tetracetic acid (EDTA) and metabolism of *Desulfuromonas palmitatis* in removing iron oxides from the bauxite. The investigation was carried out on six samples of the bauxite which contained 16-22% of Fe_2O_3. The experiment resulted in 7 to 29% of iron removal from bauxite and the most rapid and highest extraction was found in chamosite (Fe^{2+} rich compound).

In the low-grade bauxites, aluminosilicate is considered to be the major impurity. Silicate bacteria are known to have the ability to leach silicon from silicate and aminosilicate minerals [50]. *Bacillus circulans* and *Bacillus mucilaginosus* were suggested to remove silica from bauxite [23,51]. Groudeva *et al.*[23] performed a continuous leaching of silica for five days. Silicon removal from five different bauxite ore was examined by using both wild and laboratory-bred mutant strains of *Bacillus circulans* and *Bacillus mucilaginosus*. They used Ashby's basal mineral salt medium with 2% sucrose as a leaching solution. The results showed the removal of 12.5% to 73.6% of silicon present in the different ores and the residues of leaching which accounts for high values of alumina to silica ratio [38]. Silicate bacteria can be used to remove silica from bauxite to maintain the Al_2O_3/SiO_2 ratios [47]. The removal rate of silicon by silicate bacteria was different for different minerals such as bauxite, quartz, and feldspar which were found to be about 60%, 40%, 30% respectively [52-62]. The rate of silicon removal from bauxite by leaching using three strains silicate bacteria (*Bacillus circulans, Bacillus mucilaginosus,* and *Bacillus edaphics)* were examined in a single and cooperative bioleaching process. This experiment concluded that the accordance of three strains with the ratio of 2:2:1 results in a high rate of silicon leaching than in individual leaching process [63]. Two silicate solubilizing bacteria such as *Arthrobacter pascens* H19 and *Burkholderia anthina* G21 were isolated from weathered rock with higher bio-desilication ability. These bacterial strains remove Si from high silica bauxite with the aid of exo-polysaccharides and organic acid (succinic, malic, and citric acid) production. It is evidenced that the Al_2O_3/SiO_2 ratio of the bauxite ore treated with these strains were >9 thus making it suitable for alumina production by Bayer's process.

Conclusion

The presence of gangue material in low-grade bauxite ore makes it unsuitable for its utilization in aluminum industries. The removal of gangue materials from it is the foremost necessity for its valuable utilization as the Bayer's process feed. For this purpose, bio-beneficiation has proved the suitability over different drawbacks holding conventional Physico-chemical metal beneficiation techniques. Various indigenous and engineered microorganisms have successfully removed different impurities like silica, iron, and calcium from low-grade bauxite ore in the bench-scale examinations. However, there are some problems in maintaining the processing time as well as field conditions for the implementation of the process in the commercial scale. Therefore, intensive as well as comprehensive research works are foremost necessary for the fruitful commercial application of the process.

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