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Bioleaching of Indian Bauxite – Process and Performance Profiling by Indigenous Bacteria

Abstract

The main objective of this study is to upgrade lean ore of Bauxite. Up gradation of low grade ore by bioleaching process with microorganisms is a new area and offers economic benefits in commercial production. The present study include various media required for the growth of microorganism isolated from two bauxite samples analyzing 41 % and 34 % of alumina followed by isolation and characterization of the unknown microorganisms. PH and optical density was measured at definite interval of time and chemical analysis of the bioleached bauxite has been conducted by Atomic Absorption Spectrophotometer to assess the extent of up gradation of the bauxite samples. XRD and gravimetric analysis have been done to assess the purity of the produced alumina by combination of Heap leaching and solvent extraction process.

Keywords: Low Grade Alumina, Media selection, Microbial Isolates, pH, OD, AAS. , XRD.

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Introduction

The terms bioleaching and biooxidation are often used interchangeably, there are distinct technical differences between these process technologies. Bioleaching refers to the use of bacteria, principally *Thiobacillus ferrooxidans, Leptospirillum ferrooxidans* and thermophilic species of *Sulfobacillus, Acidianus* and *Sulfolobus,* to leach a metal of value such as copper, zinc, uranium, nickel and cobalt from a sulphide mineral. Bioleaching places the metal values of interest in the solution phase during oxidation. These solutions are handled for maximum metal recovery and the solid residue is discarded. Mineral biooxidation refers to a pretreatment process that uses the same bacteria as bioleaching to catalyze the degradation of mineral sulphides, usually pyrite or arsenopyrite, which host or include gold, silver or both. Biooxidation leaves the metal values in the solid phase and the solution is discarded Leaching uses microorganisms to extract precious metals, such as gold, from ore in which it is embedded. As an alternative to smelting or roasting, miners use bioleaching when there are lower concentrations of metal in ore and they need an efficient, environmentally responsible method. The bacteria feeds on nutrients in minerals, thereby separating the metal that leaves the organism's system; then the metal can be collected in a solution. *Thiobacillus ferrooxidans, Leptospirillum ferrooxidans, Thiobacillus thiooxidans, Sulfolobus* species and others have been used for bioleaching. *Acidiphilium, Sulfobacillus, Ferroplasma, Sulfolobus, Metallosphaera,* and *Acidianus* have also been used. These bacteria tolerate acids and metabolize sulfur. Weak solutions of acids are dripped through the ore and a bacterial liquor forms that is then electrolytically or chemically processed. Bioleaching does not require lots of energy but it is slow. High temperature roasting and smelting is not required, so there are decided benefits in addition to the fact that bioleaching can get metals from low grade ores.

The term bauxite is used to designate commonly occurring substrate i.e. a mixture of several hydrated aluminum oxides with considerable variation in aluminum content. Bauxite is a heterogeneous material having hydrated aluminum oxide especially gibbsite ($Al_2O_3.H_2O$) and Diaspora ($Al_2O_3.H_2O$) .Bauxite is much valuable mineral which is commonly used in the extraction of aluminum, manufacture of refractories, ceramics and chemical (Bateman,1958) .Bauxite is commonly used in the commercial production of aluminum in the Bayer's process (Henry,1985).Aluminum is virtually in all economic segments but its principle use have been developed in five major industries namely transportation ,construction, electrical, containers packing and mechanical equipment (karavaika et al ,1989) . *A .niger* utilize at least two different pathway for glucose catabolism i.e. EMP (Embden Meyerhof Paranas) pathway and pentose phosphate shunt pathway. The formation of di and tricarboxylic acids mainly occur via glycolysis. Dissolution of mineral is mainly based upon degrative action of acids protons complemented by the formation of stable complex of organic acids and hence is a combination of acidolysis and complexation phenomena. The main objective of this work is to utilize acidophilic heterotrophic fungus. *A. niger* capable of producing organic citric acids and oxalic acids from oxidation of carbon source by its metabolic of activity for alumina solubilization from low grade pail deposits of bauxite ore.

Aim of the Study

Bauxite is a heterogeneous material having hydrated Aluminum Oxide especially gibbsite ($Al_2O_3H_2O$) associated with silica and iron oxide as major gangue materials. Bauxite is commonly used in the extraction of alumina and most popular method for the commercial production of alumina is Bayer's process. In this method only high grade bauxite ore can be used with distinct economic advantage. The main objective of this study is to upgrade lean ore of Bauxite. Upgradation of low grade ore by bioleaching process with microorganisms is a new area and offers economic benefits in commercial production.

Review of Literature

In the recent age, there has been a constant demand for bioleaching techniques globally, owing to various factors such as an upshot in the demand for metal commodities as a result of urbanization, shortage of key construction metals, scarcity of skilled labors considering the risks involved in the mining process and processing of polymeric minerals which is very cumbersome with the established methods, including smelting (Brierley ,2008).Therefore, novel technologies, for leaching has come into play

Heap leaching is a well-established extractive metallurgical technology enabling the economical processing of various kinds of low-grade ores, which could not otherwise be exploited. However, despite much progress since it was first applied in recent times, the process remains limited by low recoveries and long extraction times. The most commonly practiced methods of bioleaching include following techniques – whole ore leaching and concentrate leaching process. Bioleaching also deals with water purification via cyanide destruction process, heavy metal removal, nitrate removal, hydrocarbon removal. This chapter focuses on the advantages and shortcomings of all the existing, bioleaching techniques and also discusses the variations in consortium development according to the type of the reactors in use. It will also throw light on the existing lacunae at the industrial level that is hindering the successful commercialization of this technique. *Acidithiobacillus ferooxidans* from mine water. This gram negative chemolithotroph could oxidize the sulfide part of minerals to sulphuric acid and ferrous ion to ferric at a very low pH. The industrial scale bioleaching of copper in heaps has had a chequered 400 year career. Johnson and Hallberg (2009) reported that during the 18th and 19th centuries, the practice of allowing underground shafts and adits at these mines to flood, and then periodically releasing and capturing the metal-rich waters to recover copper from the leached subterranean rocks by adding scrap iron (cementation) was adapted. This was, essentially, an ignorant application of ''in situ'' leaching, which later deliberately applied for uranium biomining from worked-out mines in Canada in 1970s. Wang et al., 2011; Wang et al., 2013; Xue et al., 2010; Yatsenko and Pyagai, 2010; Zhang et al., 2005). Wang et al. (2010) studied the extraction of scandium from bauxite residue by using HCl as leaching agent, with an L/S ratio of 5:1, an acid concentration of 6 mol/L, a reaction temperature of 50 °C and a reaction time of 1 h. Qu et al. (2013) leached rare earth elements and radioactive elements from bauxite residue by bioleaching. Over the past 20 years this technology has blossomed with annualized world copper production from the process increasing from 0.2% to approximately 8-10%. Bioleaching of copper in heaps was first recorded at the Rio Tinto mine in 17th century. The first modern industrial scale copper heap bioleach, producing 14,000tpa, commenced in 1980 at Lo Aguirre in Chile. The first stand-alone mine using copper bioleaching– solvent extraction – electrowinning was the Girilambone Copper Operation (managed by Straits Resources and commissioned 1993) in central NSW, Australia (Acevedo 2002, Ehrlich 1988, Rossi 1990).

Bioleaching involves the use of micro-organisms to extract metals from low grade ores & has been performed successfully on Earth to obtain gold, copper, nickel, zinc & cobalt. Bioleaching refers to the use of bacteria, principally Thiobacillus ferrooxidans, Leptospirillum ferrooxidans and thermophilic species of Sulfobacillus, Acidianus and Sulfolobus, to leach a metal of value such as copper, zinc, uranium, nickel and cobalt from a sulphide mineral. They are a catalyst to speed up natural processes inside ore. The bacterium uses a chemical reaction called oxidation to turn metal sulphide crystals into sulfates and pure metals. Bioleaching does not require lots of energy but it is slow. High temperature roasting and smelting is not required, so there are decided benefits in addition to the fact that bioleaching can get metals from low grade ores. Aluminum is used virtually in all economic segments but its principal have developed in five major industries namely transportation, Construction, electrical, on container and mechanical equipments. The use microorganisms in leaching and beneficiation of low grade ores and minerals are widely considered an efficient, economical and environmentally benign alternative to conventional hydrometallurgical

Benefits of bioleaching

Rich ores are on the verge of depletion, therefore it is essential to use and recover useful products from lower grade ores. Bioleaching demands lower capital investment whereas in conventional mining the operational costs are inversely proportional to the metal content of the ore. This process is suitable even for lower grade or complex ores. Bioleaching also allows the selective solublization of a particular mineral without affecting the others. Most of the byproducts and wastes are in liquid state which is much easier to manage than gaseous wastes. Moreover, there is scope for recycling of effluents. Can be used for leaching minerals present much beneath the earth's surface and is safer than conventional mining techniques. Use of indigenous microorganisms can cut the cost of buying bacterial, fungal strains. The process can be conducted in situ without the requirement of sophisticated technical support. The process environment friendly and save the company's expensive sulfur limits for emission. Reduced process control is required. Bioleaching is no more used just for the treatment of low grade ores, owing to its low economic requirements. it has also been adopted in large scale processing of copper as well as pretreatment of refractory gold.

Materials and Methods

The whole research work was completed in 120 days including all the steps starting from collection of ore sample, to testing of leacheate liquor.

Collection of Bauxite Ore

The bauxite ore used in the experiment was obtained from NALCO-region of Orissa; these bauxite ore contain 34% & 41% of alumina for the leaching experiment.

Particle Size Analysis

For bioleaching experiment the bulk ore samples containing 34% and 41% were ground and -240BSS size particle was taken for the experiment.

Isolation of Microorganisms for Leaching from *in Situ* Ore

In natural habitats micro organisms usually grow in complex mixed populations containing several species. This presents a problem for microbial because a single type of micro organism cannot be studied adequately in a mixed culture. One need a pure culture, a population of cells arising from a single cell, to characterized an individual species. There are several ways to prepare pure culture; the technique which was associated with isolation of pure culture for leaching experiment is discussed below.

The collected ore is diluted several times to reduce the microbial population sufficiently to separate colonies when plating. Then small volumes of several diluted samples contain around 30 to 300 cells is transfer to the center of an agar plate and spread evenly over the surface with a sterile bent glass rod on agar surface to that every cell grows into a completely separate colony, a macroscopically visible growth or cluster of micro organism on a solid medium, each colony represent a pure culture for the leaching experiment.

Microbial Growth Media

The microorganisms once isolated in pure form were further used for leaching experiment; sub cultured on microbial growth media. a microbial growth medium is a solid or liquid preparation used to grow, transport and store micro organisms. The media composition for growth kinetics studies of isolated micro organisms taken is Nutrient Agar Media with various concentrations of the Carbon sources as shown in below.

Type-1

Nutrient agar media (for microbial growth) Peptone-0.5g, Beef extract-**0.3g,** NACL-0.5g, Distilled water-100**ml,** Agar-1.5g**.**

Type-2

Nutrient agar media (for microbial growth) Peptone-0.5g, Beef extract-**0.6g,** NACL-0.5g, Distilled water-100**ml,** Agar-1.5g**.**

Type-3

Nutrient agar media (for microbial growth) Peptone-0.5g, Beef extract-**0.9g,** NACL-0.5g, Distilled water-100**ml,** Agar-1.5g**.**

Type-4

Composition of Sabouraud's Agar Media (SDA). Glucose-4g, Peptone-1g, Agar-2g, Distilled water-100ml

Methodology

The above mentioned medium ingredients were collected, weighed the components in an exact composition using electronic or beam balances. 100ml distilled water was added and swirled to dissolve the peptone and beef extract in a conical flask (250ml). pH was adjusted to 7.0 with the help of pH meter. Agar was added for solidification. After the preparation of medium it was then autoclaved at 15lb pressure for 15min.

Bioleaching Studies of Bauxite Ore

Bioleaching experiment was carried out in 250ml conical flasks containing 100ml of metabolite having bauxite pulp density of 2%.The initial pH of the metabolite was measured in contrast to Chemical sterile control flask were incubated on shaker at 100 rpm for (24 hrs).In the time course, samples were removed at intervals and centrifuged to remove solid suspension .Supernatants were analyzed for monitoring the pH and dissolve element.

Chemical Analysis of Leacheate Liquor by AAS (Atomic absorption spectrophotometer)

The leached suspensions were centrifuged after filtration and sent to Inspectorate Griffith India limited for testing. Metal concentration in the filtrate was analyzed after suitable dilution by using Perkin Elmer atomic absorption spectrophotometer.

Result and Discussion

Microorganisms

The *in situ* micro organisms grown on nutrient agar media showed mucoid, transparent colonies in case of both 34 and 41% ore. No growth was observed in sabouraud dextrose agar media plate showing no growth of fungus. Unknown bacteria were taken to carry out leaching experiment.

Photograph-I Growth of bacteria in of 34% ore sample

Photograph-II Growth of bacteria in of 41% ore sample

Microbial Growth Media

The microorganism obtained were further transferred to 250ml conical flask containing 100 ml of nutrient broth with varied concentration of the carbon sources which was then incubated 24 hours for confluent growth of microorganisms.

Bioleaching of Alumina

For the Bioleaching of alumina experiment 100 ml of the broth media containing varied concentration of carbon sources i.e. 0.3g, 0.6g, 0.9g of beef extract was taken in 250 ml conical flask. 2g of the ore containing 41% and 34% of alumina was added in the media. A loop full of bacterial colonies was also added in the media. The nutrient broth containing 2g ore and bacteria was then kept in the orbital shaker for leaching experiment. Initial pH was recorded and pH was observed at every 24 hours interval of time.

Observation of Alumina percentage (Al_2O_3%) for 0.3 gm carbon source for 41% ore

In case of 0.3g carbon source it is seen that there is gradual rise in pH where initial pH was 7.71 and increased to 8.35 after 5days of incubation and Al_2O_3% is 1.50. Again pH increased from 8.45 to 9.13 after 10 days of incubation indicating rise in Al_2O_3 % to 2.45 simultaneously. After 15 days of incubation it is seen that pH increased from 9.01 to 9.23 and the highest increase of Al_2O_3 to 15.50%. After 20days of incubation there is a rise in pH but Al_2O_3 % decreased as shown in fig 2. It is also seen that Al_2O_3 increased after 15 days of incubation and decreased here after as shown in fig 1 and table 1.

Observation recorded that pH gradually increased till 20 days of incubation where Al_2O_3 % increased gradually and reached maximum to 15.50% after 15 days incubation considering it as optimum level as shown in fig 3.

In case of 0.6 g carbon source it is seen that pH increased from 7.05 to 8.37 where the Al_2O_3 % being 1.77 after 5 days of incubation. After 10 days of incubation it is seen that pH increased from 8.62 to 9.37 and Al2O3 increased to 2.67. After 15 days incubation it is seen that pH decreased from 9.34 to 9.20 and Al_2O_3 decreased to1.30 %. During 20 days of incubation there is the little increase in pH with a negligible increase in Al_2O_3 In case of 0.9g carbon it is seen that there is a little increase in Al_2O_3 % after 10 days of incubation and decreased here after.

Table 1:- Variation of Al_2O_3 (%) with Reference to pH and time

Sl no	Conc.	PH	Time (days)	Al_2O_3%
1	0.3	8.35	5	1.50
2	0.3	9.13	10	2.45
3	0.3	9.23	15	15.50
4	0.3	9.47	20	1.25

Fig:-1 Variation in Al_2o_3 (%) with respect to Interval of time in case of (0.3g) of c-source

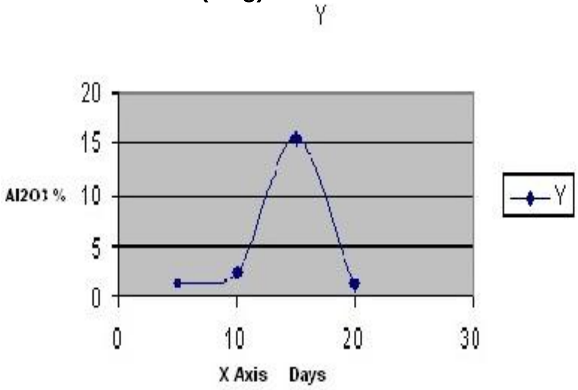

Fig 2:-Variation in pH with respect to interval of time in case of (0.3g) of c-source

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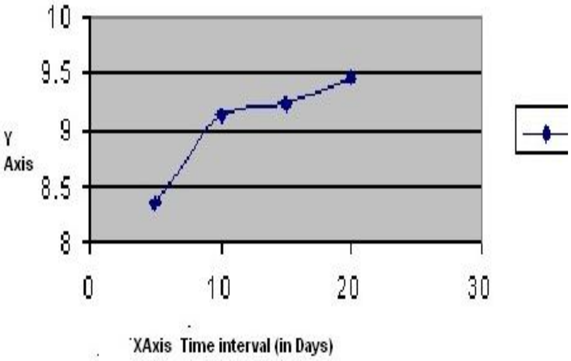
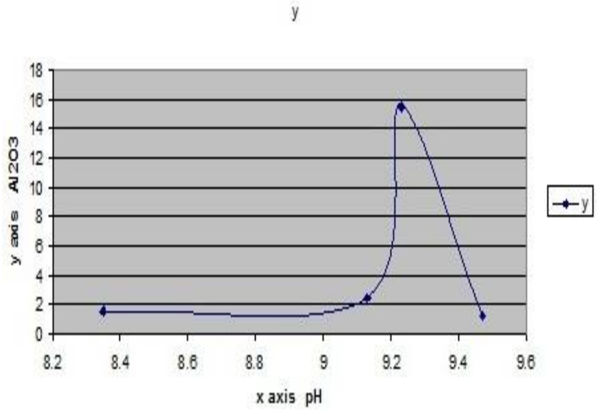


Fig 3:- Variation of Al_2O_3% with respect to PH



Observation of Alumina Percentage (Al_2O_3) for 0.3 g carbon source for 34% ore

It is observed that pH increased from 7.57 to 8.97 during 5 days of incubation with Al_2O_3being 1.20. Again there is increased in pH from 8.74 to 8.96 after 15 days incubation and Al_2O_3 % increased to 10.5 %. After 20 days of incubation it seen that there in pH from 8.96 to 9.84 with a highest rise Al_2O_3 % of 21.9 % as shown in table2, fig4 and fig5.

Table2:- Variation of Al_2O_3 (%) with reference to pH and time for 34% ore

Sl no	Conc.	pH	Time interval (days)	Al_2O_3 %
1	0.3	8.97	5	1.20
2	0.3	8.66	10	1.81
3	0.3	8.96	15	10.5
4	0.3	9.14	20	21.9

Fig4:- Variation in Al_2O_3 (%) with respect to time (In days)

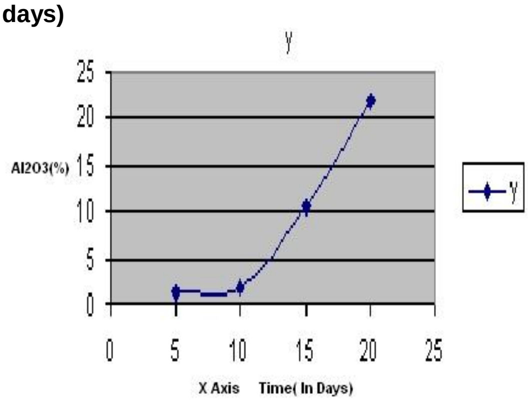
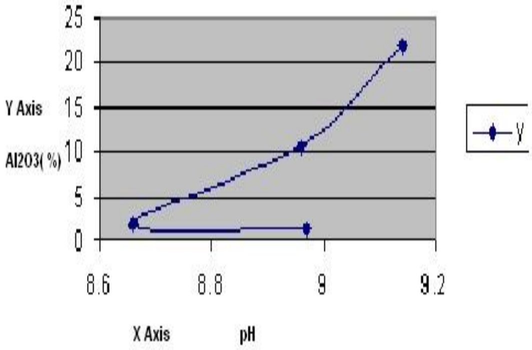


Fig5:- Variation in Al_2O_3 (%) in respect to PH



pH progressively increased during bioleaching due to alumina solubility and reached a maximum of 9.47 in case of 0.3g carbon source where alumina % being 15.50 after 15 days of incubation and then decreased. Such an effect can be justified that increasing in pH results in the ability of metabolite to dissolve alumina .Thus after 20days there was no complexation reaction occurred between alumina and organic acids released by the microorganisms.

Al_2O_3 % showed a negligible increase in case of 0.6g and 0.9g in case of 41% bauxite ore. But incase of 34% bauxite ore it observed that pH increased from 7.57 to 9.14 with a gradual increase in alumina % and reached the maximum of 21.9% Al_2O_3 after 20 days of incubation.

Our experiment showed that in both 41%and 34% ore the carbon concentration of 0.3g gave a better result in comparative to 0.6g and 0.9g of carbon concentration. Again 34% ore showed a better result in comparative to 41% of the ore. The time duration required for the leaching experiment was between 15 to 20 days.

It is also reported that pry heating ore is important as it enhances the alumina leaching and also inhibits iron leaching (Ghorvani *et .al* 2007). ''recent advances in the bioprocessing of bauxite'' Vasan *et, al* 2001 described some of the important microbiological and engineering challenges in scaling of biobenefication of bauxite. A soil bacterium Paenibacillus polymyxa was recently shown to selectively remove calcium and iron impurities from low grade bauxite (<50% Al) for abrasive and refractory application respectively.

Conclusion

In this present studies biological leaching of alumina from low grade bauxite (34% and 41% alumina) was obtained from Nalco region of Orissa. There are used in experiment were grounded & sieved to different size fraction &-240BSSsize was taken for experiment. The microorganisms were isolated from the ore by *in situ*. The strains were further subculture in nutrient agar media & incubated for 72 hrs at 30^0C to obtain the characteristics morphology. The ability of fungus in production of acids was tested in selected media containing the

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growth media in the shake media there after carried out for bioleaching technique but no result was obtained. Bioleaching experiment carried out in 250ml conical flask containing 100ml and growth media with varying concentration of carbon source i.e. beef extract. Metabolites having bauxite pulp density of 2%.The initial pH of the metabolites was in the range of 7.71, 7.05 and 7.12 in case of 41% ore sample and 7.57 in case of 34% ore sample.

During the bioleaching studies of bauxite pH progressively increased due to alumina solubilization and become maximum at 9.47, 9.47,9.64 incase of 0.3g, 0.6g, 0.9g carbon source of 41% ore sample and in case of 34% ore sample it was 9.14 The leached suspensions were centrifuged after filtration and sent to Inspectorate Griffith India limited for testing. Metal concentration in the filtrate In the case of 0.3g carbon source of 41% ore pH gradually increased till 20 days of incubation from whether Al_2O_3 % increased gradually and reached maximum to 15.50% after 15 days incubation considering it as optimum level. Al2o3 % showed a negligible increase in case of 0.6g and 0.9g in case of 41% bauxite ore. But incase of 34% bauxite ore it observed that pH increased from 7.57 to 9.14 with a gradual increase in alumina % and reached the maximum of 21.9% Al_2O_3 after 20 days of incubation. The isolated microorganisms was found to be Gram –ve, rod shaped and motile the reaming studies of bacterial screening and identification followed by creating a database and optimizing a bioreactor to create the bacterial leaching at a faster rate is going on. Literature review suggests that preheating of ore not only an enhances. The Aluminum leaching but also inhibits the iron leaching .The latter effect is considered. Very important as iron embeds the extract aluminum pregnant solution. In another report suggest that some important microbiological and engineering. Challenges in scaling of biobenefication of bauxite .A soil bacterium **Paenibacillus polymyxa** was recently shown to selectively remove calcium and iron impurities from low grade bauxite (<50%Al) for abrasive and refractory application respectively.

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