

ORIGINAL ARTICLE

Bio-Beneficiation of Iron Ore Using Heterotrophic Microorganisms

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ABSTRACT

The present studies were carried out to remove alumina and silica from iron ore as a part of the microbial process development for iron ore slime beneficiation using heterotrophic microorganisms. Iron ore containing percentage Fe₂O₃ 76.61, Al₂O₃ 6.01, SiO₂ 7.6, P₂O₅ 0.9, TiO₂ 0.2 and Fe (total) 53 leached out 15%, 8 % and 17 % of alumina and 10.6 %, 5.3 % and 20 % silica with the help of bacteria *Bacillus polymyxa*, *Bacillus sphericus* and *Pseudomonas putida* respectively, at the end of 10 days of in-situ leaching at 5 % pulp density. *Aspergillus fumigatus*, *Penicillium citrinum* and *Aspergillus flavus* were the fungus used for in-situ leaching of 10 days at 5 % pulp density showed alumina removal of 7 %, 6 % and 17 %, and silica removal of 8 %, 4 %, and 16 %, respectively. *Aspergillus flavus* and *Pseudomonas putida* were most efficient among all the bacteria and fungus used; ensuring an iron beneficiation of about 3 % by the selective removal of alumina and silica at the end of 10 days. *Bacillus sphericus* and *Penicillium citrinum* leach out iron simultaneously with alumina and silica. Apart from this, growth characteristics of *A.flavous* and *P.putida* have been studied in which bacteria showed rapid growth rate as compared to fungus whereas fungus has given more biomass than bacteria.

Keywords: Microorganisms, iron ore, biobeneficiation, silica, alumina

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INTRODUCTION

Metal-winning processes based on the activity of microorganisms offers an economic, eco-friendly and sustainable alternative for the mining industry, when the recovery of metals from ores; specially lean grade using conventional techniques is becoming very expensive due to high energy and capital inputs accompanied by environmental burden. Bio-beneficiation refers to removal of undesirable mineral components from an ore by micro organism which bring about their selective removal and thereby, enriching the desired mineral constituent in the solid ore matrix mediated by a number of surface chemical and physiochemical phenomenon. Iron ore is the raw material used to make pig iron which is one of the main constituent used in steel making. High percentage of alumina and silica present in iron ore has adverse effect on reducibility, coke rate, productivity and blast furnace operation, for steel making. 98 % of the mined iron ore is used in steel making. Weathering of gangue, especially aluminosilicates is a microbial activity in bioleaching that has received very little consideration with a few exceptions [1- 6]. Heterotrophic microorganisms degrade the aluminosilicate by using the soluble low molecular weight metabolites, organic acids and amino acids etc. Fundamental research efforts should be directed towards heterotrophic leaching and /or beneficiation of silicate carbonate and oxide ores [7]. Since ores are not sterile and cannot be sterilized on a commercial scale, heterotrophic leaching poses some process development and design challenges that autotrophic leaching does not [7]. In accordance with the wet chemical and instrumental techniques (XRF), the iron ore sample obtained from Guali mines, Orissa, India was found to contain about 76-78 % Fe₂O₃, apart from Al₂O₃, SiO₂, P₂O₅, and TiO₂ as undesirable components. The present investigation demonstrated the bio-beneficiation of 'Guali' iron ore using *Bacillus polymyxa*, *Bacillus sphericus*, *Pseudomonas putida*, *Aspergillus fumigatus*, *Penicillium citrinum* and *Aspergillus flavus*. The ore beneficiation by heterotrophic bacteria is carried out by the secondary metabolites produced by these micro organisms [7]. It is important to determine the onset of the stationary phase as the production of secondary metabolites occurs at this phase. Hence, experimental

growth studies were conducted to determine the commencement of the stationary phase for one bacterial and one fungal strain.

METHODS

Sample

Iron ore sample was obtained from Guali iron ore mines, India. The sample was analyzed by wet chemical and instrumental techniques (XRF or X-ray fluorescence analysis) (Vogel, 1978). The sample was collected, ground, dried in a hot air oven (105 °C) and analyzed by standard methods (Vogel, 1978).

Microorganisms

Bacillus polymyxa, *Bacillus sphericus*, *Pseudomonas putida*, *Aspergillus fumigatus*, *Penicillium citrinum*, *Aspergillus flavus* were used for the study. Bacterial strains were maintained on nutrient agar and fungal strains on potato dextrose agar slants, respectively. Bromfield medium containing (g/L) sucrose 20, yeast extract 1, K₂HPO₄ 0.25, NH₄SO₄ 0.25, MgSO₄ 0.75, sodium bisphosphate 0.30 and having pH of 6.8 ± 0.2 was used for beneficiation studies using the aforementioned bacterial and fungal strains.

Beneficiation Process

Beneficiation with bacteria

In situ leaching experiments with *Bacillus polymyxa*, *Bacillus sphericus* and *Pseudomonas putida* were carried out in 100 ml of Bromfield medium in 250 ml Erlenmeyer flask under sterile conditions at a pulp density, temperature and agitation speed of 5 %, 35 °C and 150 rpm, respectively. Inoculation was done with 10% inoculum (v/v) containing 1 × 10⁸ cfu/ml of *Bacillus polymyxa*, *Bacillus sphericus*, *Pseudomonas putida* and incubation time was 10 days. At the end of experiments, solid residue was separated by filtration through medium fast filter paper, dried in hot air oven and analyzed for Al and Fe. The pH of the filtrate was determined with help of pH meter.

Beneficiation with fungus

Aspergillus fumigatus, *Penicillium citrinum* and *Aspergillus flavus* were the fungus used for in-situ leaching. It was done in 100 ml of Bromfield medium under sterile conditions. Iron ore sample was added at 5% pulp density (w/v). Inoculation was done with 10% inoculum (v/v) containing 1 × 10⁶ spores/ml of the aforesaid spores. Incubation temperature and agitation speed were 35 °C and 150 rpm, respectively, and incubation time was 10 days. At the end of experiments, solid residue was separated by filtration through medium fast filter paper, dried in hot air oven and analyzed for Al and Fe. The pH of the filtrate was determined with help of pH meter.

Growth Study

Kinetic growth study of bacteria

Pseudomonas putida has given good result in comparison to other bacteria, so the growth studies of *P. Putida* has been presented here. The bacterium was cultured with 200ml nutrient broth in 250ml standard Erlenmeyer shake flask in a biological incubator shaker at 100 rpm and 30°C. To avoid the lag phase the culture was kept over night around 12 hrs. For the estimation of biomass, the absorbance of the media was studied with respect to time with the help of Jasco V-530 UV/VIS spectrophotometer. The absorbance values were taken at a time interval of 30 minutes until the stationary phase has been reached. Vertxing has been done before every reading in order to get homogenized sample for accurate absorbance values.

Biomass growth study of fungus

The absorbance study for fungus is not possible as they form spores (mat like) in the broth. So the biomass weight for the fungus was directly measured. For this purpose the Bromfield media in 6 different flasks were kept in the shaker to allow them for growth after inoculation. Each day one flask was taken and filtered for the biomass by using filter paper. The filter paper with biomass was kept in hot air oven at temp 90°C. After the filter paper has been dried completely, the weight of that filter paper was determined, hence, the dry weight of the fungal biomass.

Effect of Ph on Growth Study

For this purpose, Bromfield media at five different pH values (7, 6.5, 6, 5.5, and 5) in five different flasks were taken. After inoculation, those were kept for five days in shaker. After incubation the dry weights of the biomass was determined by using the same method mentioned in section 2.4.2.

RESULTS AND DISCUSSION

Chemical Analysis of Iron Ore

Complete chemical analysis of Guali iron ore revealed that the sample on an average contained 53 % total iron and alumina concentration in the sample was quite high (6.012 %), besides this, the ratio of SiO₂/Al₂O₃ in the original ore was also very high contradicting to blast furnace chemistry. An iron ore containing more than 58-60 % iron is considered suitable for steel making by existing technology. All the

facts accelerated the endeavor to make this pristine ore to be suitable for steel making by using microorganisms.

Bioleaching Experiments

Aspergillus sp., *Bacillus* sp. and *Pseudomonas* sp. are known to be involved in the leaching and beneficiation processes of silicate ores and minerals [1-4]. The solubilizing action by microorganisms may involve the cleavage of Si–O–Si or Al–O framework bonds, or the removal of cations from the crystal lattice of aluminosilicate causing the subsequent collapse of silicate lattice structure. In situ leaching with *Aspergillus fumigatus*, *Penicillium citrinum* and *Aspergillus flavus* resulted in 7 %, 6 % and 17 %, removal of alumina, respectively, (Fig.1). *Bacillus polymyxa*, *Bacillus sphericus* and *Pseudomonas putida* ensured an alumina removal of 15 %, 8 % and 17 %, respectively, (Fig.1). In situ leaching with *Aspergillus fumigatus*, *Penicillium citrinum* and *Aspergillus flavus* resulted in 8 %, 4 % and 16 %, removal of silica, respectively, (Fig.2). *Bacillus polymyxa*, *Bacillus sphericus*, and *Pseudomonas putida* ensured silica removal percentage of 10.6, 5.3 and 20, respectively, (Fig.2). According to the XRF studies, *Aspergillus flavus* and *Pseudomonas putida* catalyzed the increment of Fe_2O_3 percentage in the treated iron ore by 3 % at the end of 10 days by their selective removal of alumina and silica. This study also revealed the simultaneous iron removal by microorganisms like *Bacillus sphericus* and *Penicillium citrinum* while removing silica and alumina. Iron ore beneficiation results involving various microorganisms are shown in (Fig. 3). The neutral pH at the beginning for all the beneficiation experiments with fungi and bacterial strains turned to acidic ones at the end. As far as the utilization of sugar is concerned some of the fungal strains like *Aspergillus fumigatus* utilize sugars like glucose and sucrose equally well.

Growth Study Experiment

Aspergillus flavus and *Pseudomonas putida* has shown very good results in leaching the undesirable components like alumina and silica (17% & 20% respectively). So we preferred to study the growth characteristics of those strains.

Bacterial growth study

Pseudomonas putida had shown a decent growth rate when incubated in nutrient media. In the growth curve, the exponential phase is consistent with a slope ≈ 0.2 units/hr (Fig. 4). The reading started after 12hrs. The stationary phase reached nearly after 24hrs from the inoculation.

Fungal growth study

Aspergillus flavus has shown a very slow growth rate when compared to bacterial strain *Pseudomonas putida*. The growth curve reached its exponential phase nearly after 24hrs. It took five days to reach the stationary phase (Fig. 5).

Biomass Growth and pH

It has been observed that the pH of the media is continuously decreasing with the increase in biomass growth for *Aspergillus flavus*. This can clearly show in figure (Fig. 6).

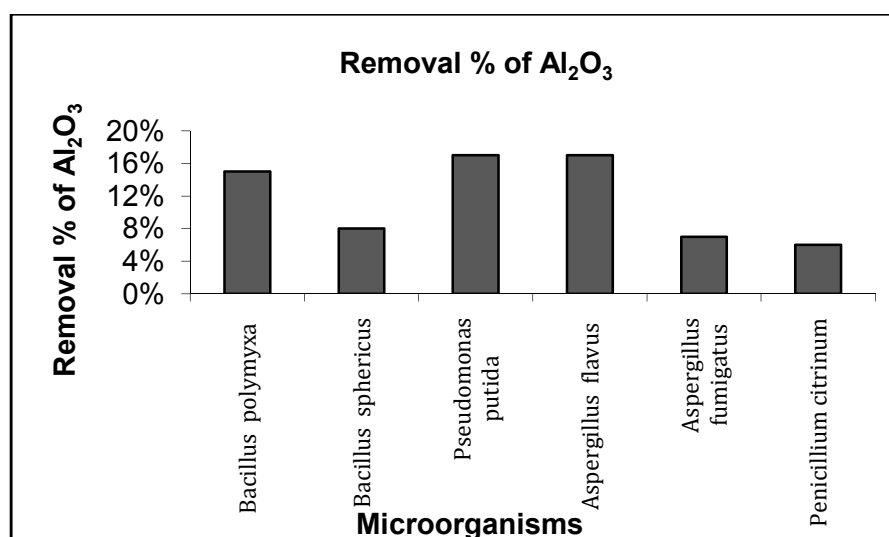


Figure 1: Removal percentage of Al_2O_3 using different fungal and bacterial strains.

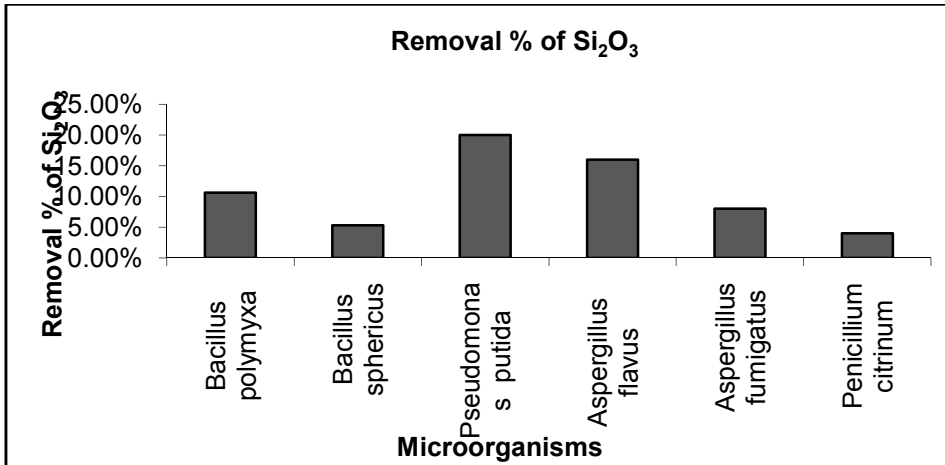


Figure 2: Removal percentage of Si₂O₃ using different fungal and bacterial strains.

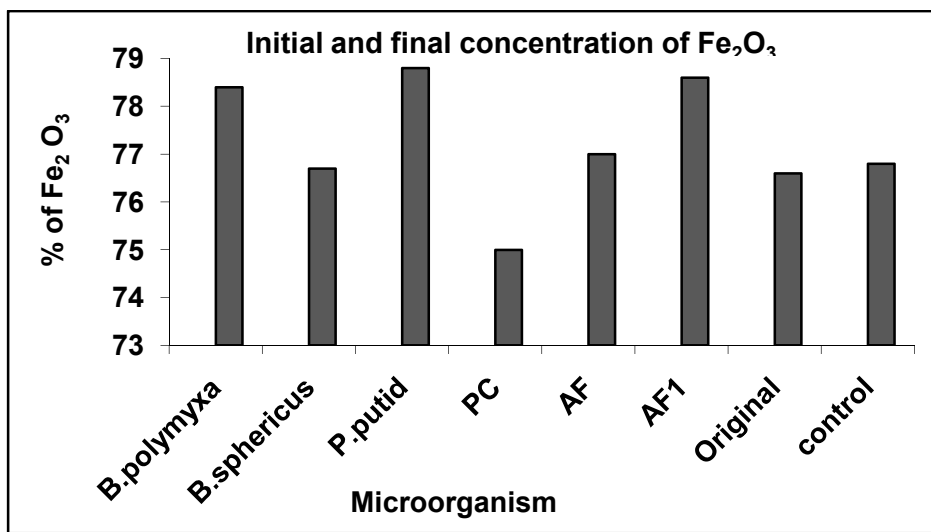


Figure 3: Initial Fe₂O₃ concentration of the Iron ore and final Fe₂O₃ concentration of the Iron ore after the action of different micro organisms (determined by XRF).

**AF: *Aspergillus fumigatus*; AF1: *Aspergillus flavus*; PC: *Penicillium citrinum*

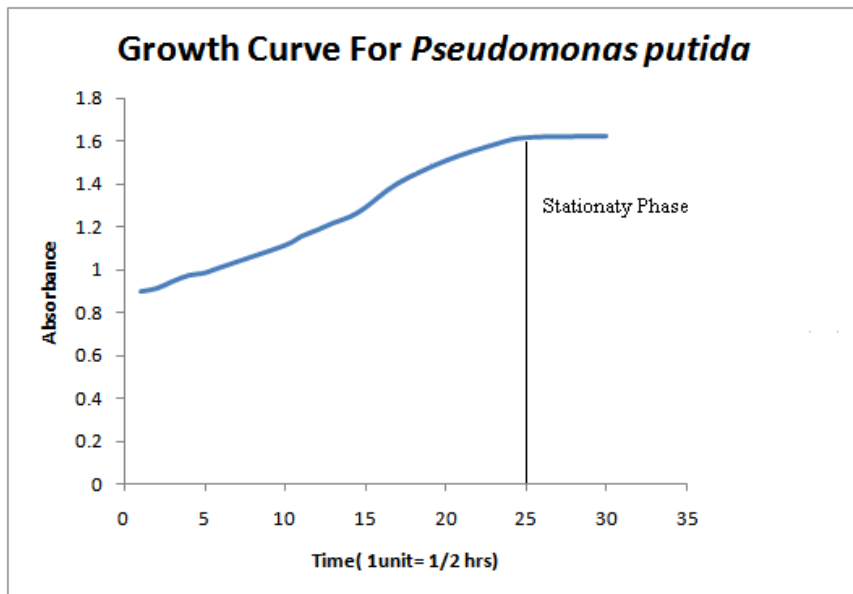


Figure 4: Growth curve for *Pseudomonas putida*

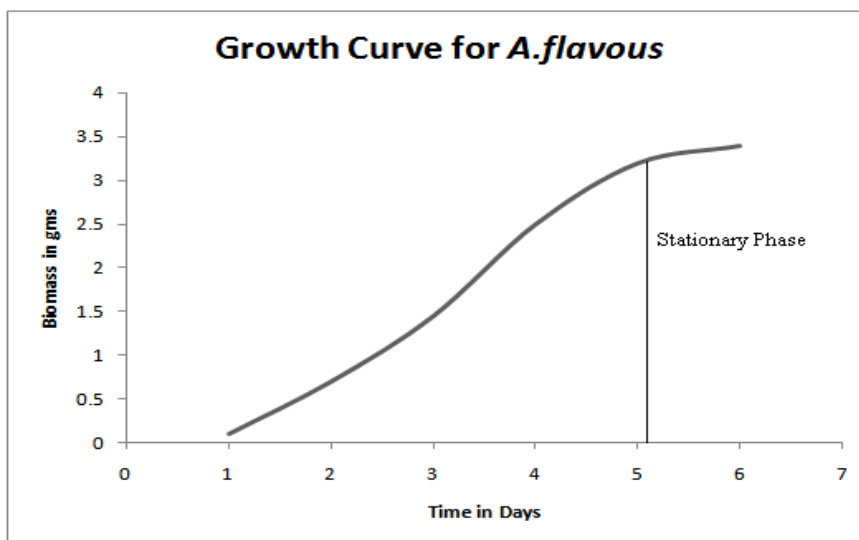


Figure 5: Growth curve for *Aspergillus flavus*

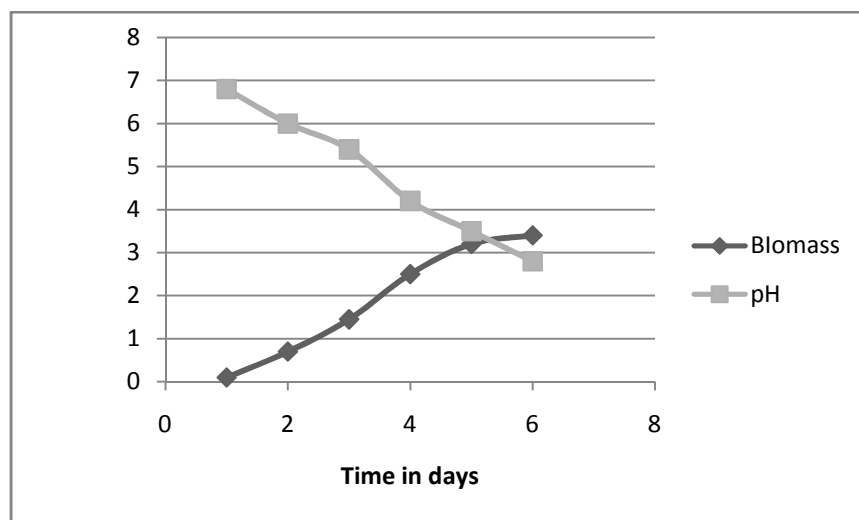


Figure 6: Decrease of the pH with biomass growth in *Aspergillus flavus*

CONCLUSIONS

The alumina present in the iron ore poses problem of handling high viscous solution in blast furnace operation. In situ leaching of Guali iron ore by *Aspergillus fumigatus*, *Penicillium citrinum* and *Aspergillus flavus* removed about 7 %, 6 % and 17 % of alumina in 10 days at 5% pulp density. *Bacillus polymyxa*, *Bacillus sphericus* and *Pseudomonas putida*, removed about 15 %, 8 % and 17 % of alumina in 10 days at 5% pulp density. Apart from alumina, 10.6 %, 5.3 % and 20 % silica were removed with the help of *Bacillus polymyxa*, *Bacillus sphericus* and *Pseudomonas putida*, respectively, in 10 days at 5% pulp density. *Aspergillus fumigatus*, *Penicillium citrinum* and *Aspergillus flavus* removed 8 %, 4 %, and 16 % silica, respectively, at the end of 10 days with 5% pulp density. *Aspergillus flavus* and *Pseudomonas putida* were most efficient among all the bacterial and fungal strains used; ensuring iron beneficiation of about 3 % at the end of 10 days. *Bacillus sphericus* and *Penicillium citrinum* leach out iron simultaneously with alumina and silica. For fungal strains like *Aspergillus fumigatus*, a cheap carbohydrate source like sucrose can be used in place of glucose, which may contribute to the overall economy of the process. From the growth studies of bacterial and fungal strains, it can be concluded that leaching with heterotrophic bacteria is less time consuming or faster than in comparison with fungal strains. The earlier onset of stationary phase for the bacterial strain in comparison to fungal strain supposed to be responsible for accelerated leaching out of alumina and silica from the iron ore; hence, *Pseudomonas putida* is a potential microorganism for economic leaching/beneficiation. From the aforesaid facts, the bio-beneficiation of iron ore by incrementing iron percentage and removing undesirable silica and alumina, from the pristine ore, hence altering the alumina to silica ratio suitable for blast furnace operation seemed to be a promising and eco-friendly alternative.

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REFERENCES

1. Huang, W.H., Keller, W.D., "Organic Acids as Agents of Chemical Weathering of Silicate Minerals", Nat. Phys. Sci., 1972, 239, 149-151.
2. Bennett, P. C., Melcer, M. E., Siegel, D.I., Hassett, J. P., "The Dissolution of Quartz in Aqueous Solutions of Organic Acids at 25^o C", Geochim. Cosmochim. Acta., 1988, 52, 1521- 1530.
3. Welch, S. A., Ullman, W. J., (1993) "The Effect of Organic Acids on Plagioclase Dissolution Rates and Stoichiometry", Geochim. Cosmochim. Acta., 57, 2725-2736.
4. Ullman, W. J., Kirchman, D. L., Welch, S.A., Vandevivere, P., (1996) "Laboratory Evidence for Microbially Mediated Silicate Mineral Dissolution in Nature", Chem. Geol., 132, 11-17.
5. Pradhan N., Das, B., Gahan, C.S., Kar, R.N., Sukla L.B., (2006) "Beneficiation of Iron Ore Slime using *A. niger* and *B. circulans*", Bioresource Technology, 97, 1876-1879.
6. Natarajan, K. and Deo, N., (2000) "Role Of Bacterial Interaction and Bioreagents in Iron Ore Floatation", International Journal of Mineral Processing, 62, 143-157.
7. Ehrlich, H. L., (2001) "Past, Present and Future of Biohydrometallurgy", Hydrometallurgy, 59, 127-134.

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