Copper and Nickel Extracting Fungi from Low and Lean Grade Ores From Mine Areas of Chhattisgarh

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Abstract: Bioleaching is most effectual and low cost method of recovery of metals from low and lean grade ores against conventional chemical techniques as it requires less energy inputs for the recovery of small quantities of metal left after physical processing of high grade ores. Four potent fungi belonging to genera Aspergillus and Penicillium were explored for copper and nickel extraction from low and lean grade ores. Aspergillus niger NFCCI-3303 extracted higher amount of copper and nickel as compared to other three isolated fungi.

Keywords: Copper, Nickel, Low grade ores, Acid production, Aspergillus, Penicillium

Introduction

Chhattisgarh is a newly carved state from Madhya Pradesh in the year 2000 and is located in central India. It is the 10th largest state in India, with an area of 135,194 km². It is one of the fastest-developing states of the country. Chhattisgarh is one of the foremost mineral rich states of India. Eight mines of Chhattisgarh region viz., Lakshman coalfield mine, Kusmunda mine, Dalli mine, Rajhara mine, BIOP mine, Hirri mine, Rawan mine, Nandini mine and one ore-dumping site of Bhilai Steel Plant were explored for the study. Twenty nine acidophilic fungi were isolated from these study sites. After quantitative acid production, four isolates were selected for screening purpose using chalcopyrite and nickel laterite as leaching material.

Microbes are principally exploited for commercial application in industries. Their ability to solubilize metals from solid material has been explored in the recent past which has opened completely new prospects for their application in mineral biotechnology (Sabat & Gupta, 2009). Microbes of mining environments have become very important for current investigations. Several species of fungi have been used for the bioleaching process. Enormous literature has been published concerning the ability of fungi to extract metals from different resources (Ghobani et al., 2008; Anjum et al., 2009; Nouren et al., 2011; Behera & Shukla, 2012 & Choudhary et al., 2014). Different heterotrophic microorganisms are widely distributed all over the mine areas. In past many researchers have emphasized on isolation of fungi for metal dissolution which can be useful towards biohydrometallurgy (Mishra et al., 2008; Bohinder et al., 2009; Behera et al., 2010; Gharich et al., 2013; Amin et al., 2014 & Kumari et al., 2015). In the present study acidophilic fungi was isolated from different mine areas of Chhattisgarh region and best acid producing fungi was used for efficient copper and nickel solubilization from respective ores.

Materials and Methods

1.1 Isolation of Fungi

The fungus was isolated from eight mine areas of Chhattisgarh region viz., Laxman coalfield mine (22.35°N & 82.50°E), Kusmunda mine (22.35°N & 82.75°E), Dalli mine - Rajhara mine (20.56°N & 81.05°E), BIOP mine (18.60°N & 81.25°E), Hirri mine (21.98°N & 82.31°E), Rawan mine (21.24°N & 81.64°E), Nandini mine (21.37°N & 81.42°E) and one ore-dumping site of Bhilai Steel Plant (21.18°N & 81.39°E). Based on quantitative acid production four potent fungal isolates were selected for screening purpose viz., Aspergillus niger gr. NFCCI-3303 (LAK-2), Aspergillus niger gr. NFCCI-3307 (DM-1), Penicillium sp. NFCCI-3305 (HM-6) and Penicillium sp. NFCCI-3306 (KUS-2).

1.2 Ore Material

The ore material for leaching studies was acquired from various mine sites. The low grade chalcopyrite ore was collected with the assistance of faculty of School of Studies in Geology and WRM, Pt. Ravishankar Shukla University, Raipur and the nickel laterite was collected from Sukinda mine (21.03°N & 85.77°E), Orissa, India.

1.3 Characterization of ore sample

The elemental composition of the ores was determined by Scanning Electron Microscope (Zeiss EVO18 special Edition equipped with EDX ‘Oxford Instruments’ X-Max®) using Aztec software. The mineral composition was determined by XRD (X-Ray Diffraction) using X’pert powder ‘PANalytical’. The results obtained were analyzed with the help of available XRD data for minerals using the High Score plus software version 3.0e.

1.4 Bioleaching efficiency:

The fungal isolates were screened for solubilization of metals from collected ores. All bioleaching experiments were conducted using modified Czapek-Dox minimal
medium supplemented with 1% of ground chalcopyrite or 1% nickel laterite ores (100 mesh). 100 ml of the medium in 250 ml Erlenmeyer flask was inoculated with 4 mm fungal disc. Control flask was separately maintained without fungal inoculum. All the flasks were incubated at room temperature (28±2°C) on a rotary shaker (100 rpm) for 10 days. After 10 days, mycelia were removed from the medium using Whatman No. 1 filter paper; 5 ml culture filtrate was taken and diluted with 5% HCl to 100 ml in volumetric flask. The concentration of soluble copper and nickel were determined by atomic absorption spectrophotometer (LABINDIA, AA8000) with an air-acetylene flame and expressed as g/L. Metal recovery or leaching efficiency was calculated as follows:

Metal recovery % = Metal content in leachate / Initial metal content in ore × 100

1.5 Preparation of standard copper and nickel solution

Standard copper and nickel metal solution (1 g/L; Merck), were used for the preparation of respective standard copper and nickel solution by diluting with double distilled water for Atomic absorption spectrophotometer (LABINDIA, AA8000).

Results

The X-Ray diffraction pattern of the chalcopyrite revealed that the main mineralogical phase identified was bornite, quartz, chalcopyrite, covellite and pyrite (Figure 1) whereas nickel lateritic ore was mainly associated with chromite, maghemite, magnetite, goethite, ferricydrite and quartz (Figure 2). The EDX analysis reveals that the percentage of copper and nickel was 2.76% and 0.42% along with other trace metals. The leaching efficiency of copper by all the four fungal isolates is shown in Figure 3. The solubilization of copper was found to be between 3.64±1.27 to 7.71±0.52 g/L by the fungal isolates. Aspergillus niger gr. NFCCI-3303 (LAK-2) exhibited maximum solubilization of copper from the respective ore (7.71±0.52 g/L), followed by Aspergillus niger gr. NFCCI-3307 (DM-1) with a value of 5.23±0.51 g/L and Penicillium sp. NFCCI-3305 (HM-6) with a value of 3.64±1.27 g/L. The isolate Penicillium sp. NFCCI-3306 (KUS-2) recorded minimum solubilization (3.64±1.27 g/L). The percentage of extraction of the ore by four fungal isolates ranged from 13.18% to 27.92%. The leaching efficiency of nickel by the same fungal isolates is presented in Figure 4. The range of solubilization of nickel was recorded to be within 0.04±0.01 to 0.37±0.03 g/L. The maximum solubilization of nickel was recorded for Aspergillus niger gr. NFCCI-3303 (LAK-2) to a tune of 0.37±0.03 g/L. The percentage of extraction was 8.81%. The minimum solubilization was exhibited by Penicillium sp. NFCCI-3306 (KUS-2). The percent extraction of nickel was high with Aspergillus niger gr. NFCCI-3303.

Figure 1: X-ray diffraction analysis of chalcopyrite ore showing peak of bornite, quartz, chalcopyrite, quartz, covellite and pyrite. The x-axis is 2θ (angle of diffraction) and the y-axis is the intensity.
Discussions

The chalcopyrite and lateritic nickel ore samples were evaluated to establish their suitability to serve as a raw material for copper and nickel leaching. The mineralogical characterization of the chalcopyrite ore by XRD-analysis revealed the presence of chalcopyrite and covellite as major phase along with other associated iron-bearing phases like magnetite ($\text{Fe}_3\text{O}_4$) and pyrite ($\text{FeS}_2$). The elemental composition of the chalcopyrite EDX analysis indicated that it was a low grade ore with 2.76% of copper along with other trace elements, which is uneconomical for commercial exploitation through conventional methods. The categorization of an ore to fit in low and lean category varies not only with the element but also with geographical region. Baba et al. (2011) exploited low grade chalcopyrite ore having 7.16% copper present in it for the biooxidation by a mixed bacteria consortium predominantly having *Acidithiobacillus ferrooxidans* (Nakade, 2012) used low grade chalcopyrite (having 32.8% copper) for bioleaching of copper by *Thiobacillus thiooxidans* N-9.
The X-ray diffraction pattern of raw nickel lateritic ore mainly associated with chromite, magnetite, goethite, ferrhydrite and quartz. Behera et al., (2010) studied the X-ray diffraction of raw overburden lateritic ore and reported the presence of the goethite, a hydrated iron oxide (FeOOH). The elemental analysis by EDX in the present study on laterite nickel ore revealed that the sample of raw ore was typically a low grade ore with the presence of 0.42% nickel along with other metal. Laterite ore is highly weathered material in which the main nickel bearing mineral is the hydrated iron oxide or goethite (FeOOH). Behera et al. (2010) reported a range of 0.4-0.9% nickel in chromite mine of Sukinda Valley, Orissa.

The efficient four acid producing strains viz., Aspergillus niger gr. NFCCI-3303 (LAK-2), Penicillium sp NFCCI-3306 (KUS-2), Aspergillus niger gr. NFCCI-3307 (DM-1) and Penicillium sp NFCCI-3305 (HM-6) were selected for bioleaching of copper and nickel metals from their respective ores. Aspergillus and Penicillium has been documented for their better biohydrometallurgy process for the recovery of metals (Castro et al, 2000; Mulligan & Kamali, 2003; Zhou et al, 2008 & Siddiqui et al, 2009). The bioleaching studies in present context revealed that both the Aspergillus niger strains isolated from two different mines showed better potentiality for copper and nickel extraction from their respective ores over Penicillium sp. However, among the two Penicillium sp., Penicillium sp NFCCI-3305 showed better leaching as compared to Penicillium sp NFCCI-3306. Aspergillus niger has been reported to exhibit good potential in generating a variety of metal solubilization organic acids during cellular metabolism (Mulligen et al., 2004; Behera et al., 2011; Marcincakova et al., 2015). Also, A. niger has been documented to be more efficient in solubilizing nickel as compared from the leaching ability of A. fumigates and Penicillium sp (Bohindar et al., 2009). It has been suggested that several species of fungi can be used for biomining (Siddiqui et al., 2009). They reported that Aspergillus niger and Penicillium simplicissimum were the best strains for the mobilization of metals. Thus in the present study Aspergillus niger NFCCI-3303 was found to be more effective for leaching purpose.

Acknowledgments

Grateful thank are due to the Head, School of Studies in Life Sciences, Pt. Ravishankar Shukla University, Raipur for providing the research facilities. One of us (RK) is thankful to UGC, New Delhi for financial assistance (SRF) in form of MANF. The grants from DST-FIST and UGC-DRS-SAP to the department are also gratefully acknowledged.

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