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Biological leaching of nickel and cobalt from lateritic nickel ore of Sukinda mines

Smaranika Mohapatra*,†, Chandan Sengupta, Bansi Dhar Nayak*, Lala Bihari Sukla*, and Barada Kanta Mishra***

*Institute of Minerals and Materials Technology (CSIR), Bhubaneswar, Orissa-751013, India
**Department of Botany, Kalyani University, West Bengal-741235, India
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Abstract−In the present study lateritic nickel ore was used for bacterial leaching using a mixed consortium of mesophilic acidophiles. The microorganisms were adapted to 1 gram nickel/L prior to leaching. For the experiments, lateritic ore in different forms such as raw, roasted, roasted ore presoaked in dilute sulphuric acid and palletized pretreated roasted (400 °C and 600 °C) ore were taken. The leaching experiments were conducted in 9 K^+ with 40 L capacity bioreactor using 10% (v/v) inoculum concentration at 10% (w/v) pulp density. The aeration was maintained at 2-3 L/min and the speed of agitator and temperature at 400-500 rpm and 35 °C. The maximum extraction of nickel and cobalt was observed with pretreated ore (600 °C) at 10% pulp density (77.23% and 73.22%) respectively within 31 days at pH 1.5 and least extraction in case of raw ore i.e., 9.47% nickel and 41.12% cobalt respectively.

Key words: Lateritic Nickel Ore, Roasted Ore, Pretreated Ore, Nickel, Cobalt, Mesophilic, Acidophilic, 40 L, Bioreactor

INTRODUCTION

New resources for metals must be developed with the aid of novel technologies. Improvement of already existing techniques can result in metal recovery from sources that have not been of economical interest until today. The problem is that the recovery of metals from low and lean grade ores, using conventional techniques is very expensive due to high-energy capital inputs required. Another major problem is environmental expenses due to the high level of pollution from these technologies. Therefore bioleaching have come into perspective. It holds the promise of dramatically reducing the capital costs and the opportunity to reduce environmental pollution.

Nickel and cobalt are strategic metals of vital importance to many modern industrial processes. The world's nickel reserve is about 71 million tons and nickel laterites, a low grade oxide ore represents the bulk or about 85% of known nickel and a greater quantity of cobalt global reserves [1,2]. The only significant deposit of lateritic nickel ore in India is in the ultra basic belt of Sukinda, Orissa which are not yet commercially exploited. Biohydrometallurgy has been developed as a discipline and an alternative process for extraction of metals like nickel, cobalt, uranium, gold, copper etc. In view of the present scenario, the continued depletion of high grade nickel sulphides ores, has led to the progress of bioleaching processes in recovering nickel from low grade laterite ores [3-5]. A number of genera of bacteria have been shown to be important in biomineralization: *Acidithiobacillus*, *Leptospirrillum*, *Acidiphilium*, *Sulphobacillus*, *Ferroplasma*, *Sulpholobus* and *Acidianus*. Recent studies have shown the amenability of lateritic ores for bioleaching by using heterotrophic micro-organisms [6-9]. *Penicillum* and *Aspergillus* have been reported to leach nickel from lateritic ore [3,10]. However there is much difference in the amenability of the minerals towards biological leaching. Nickel extraction appears from the silicate ores is more efficient and from lateritic ores is not so effective [3,5].

Bioleaching is very attractive as it is environmental friendly but the leaching kinetics is very slow. This technique is slowly gaining importance in the field of waste treatment [11,12]. In order to make faster the leaching kinetics of the biohydrometallurgical processes biological leaching technology has been introduced. The development of industrial mineral processing in bioreactors has utilized sulphur-oxidizing acidophiles [13]. The development of bioreactor process for nickel and copper from mineral sulphide flotation concentrates has reached pilot plant scale [14]. Commercial applications include processing of refractory gold concentrates to release gold for conventional recovery and the bioleaching of copper in heap and dump leach operations. Commercial application of stirred tank bioleaching for the recovery of copper has also developed rapidly in recent years with the installation of very large bioreactors.

Bioreactor technology consists of three phases such as solid, aqueous and gaseous phase. Thorough mixing of the above three phases is very essential for the effective encounter of solid particles with microorganisms as well as chemically active molecules. The most significant factors adversely affecting microbial growth are non-availability of oxygen, accumulation of metabolites, incorrect temperatures, hydrogen ion concentration and metal toxicity [15]. In order to avoid the above necessary needs bioreactor technology is the best possible option.

Acidithiobacilli is considered to be the most effective genus that has been used for metal extraction from sulphide ores on a technically and economically large scale. Therefore, an attempt was made to extract nickel and cobalt using different forms of lateritic ore using a mixed consortium of mesophilic acidophile predominantly *Acidithiobacillus ferrooxidans.* It was reported earlier that nickel and cobalt extraction was not very significant with the raw lateritic ore [16]. The leaching studies were conducted in bioreactor with different forms of lateritic nickel ore such as raw, roasted (300 °C), roasted ore presoaked in dilute sulphuric acid and palletized pretreated roasted (400 °C and 600 °C) ore. The results has been presented and discussed in this investigation.

†To whom correspondence should be addressed.
E-mail: mohapatra.smaranika@gmail.com

MATERIALS AND METHODS

1. Lateritic Nickel Ore Samples

Nickel ore samples were obtained from major deposits of Sukinda Mines, Orissa, India. In this lateritic nickel ore, nickel is reported to be associated with goethite matrix and cobalt is associated with manganese [17]. Laterite is a highly weathered material rich in secondary oxides of iron (goethite, a hydrated iron oxide such as α-FeO (OH) or $Fe_2O_3 \cdot H_2O$), aluminium or both but devoid of bases and primary silicates and may contain abundant quartz and kaolinite. It often contains minor amounts of nickel, cobalt and chromium [18].

For experimental purpose four different forms of the lateritic nickel ore was taken and the ore taken as such was designated as raw ore. The second form of lateritic ore roasted (calcinated) at 300 °C for 5 hours to convert the goethite to hematite in order to release nickel from goethite matrix. This nickel ore subjected to calcinations is henceforth designated as roasted ore. The conversion of goethite to hematite takes place at around 360 °C [19]. The third and fourth form of ore samples are homogenized by grinding and palletized in different size fractions. The palletized ore were pretreated by roasting in a muffle furnace at different temperatures such as 400 °C and 600 °C respectively. This sample was designated as palletized pretreated lateritic nickel ore and changes the mineralogical characteristics of the ore in order to increase the leaching efficiency.

2. Chemical Analysis

Raw, roasted and palletized pretreated lateritic nickel ore samples were digested and suitable dilutions were done for analysis of nickel, cobalt, iron, chromium and manganese by Atomic Absorption Spectrophotometer (AAS). The chemical analyses of the raw, roasted and palletized pretreated ore are reported in Table 1.

3. Mineralogical Analysis

Mineralogical analysis of the raw ore, roasted ore (300 °C) and the palletized pretreated (400 °C and 600 °C) ore of the nickel lateritic samples were analyzed using high-resolution synchrotron based X-ray Diffractometer (XRD) and by optical microscopy. The raw, roasted and palletized pretreated nickel ore revealed the presence of goethite a hydrated iron oxide (α-FeOOH) and hematite (Fe_2O_3) respectively (Fig. 10).

4. Microorganism

A laboratory stock culture of mixed mesophilic acidophiles bacterial consortium (predominantly *Acidithiobacillus* species) strain was used for leaching experiments. *Acidithiobacillus* is a strictly aerobic, gram −ve, rod shaped and chemoautotrophic bacterium which derives the energy for its metabolism from the oxidation of inorganic iron and reduced sulphur compounds [20]. There have been numerous papers referring to the metabolic properties of these organisms and its ability to achieve optimum growth under strongly acidic conditions, i.e., pH≤2.5 [21-25]. The microorganism was grown in 9 K^+ media of Silverman and Lundgren [26] containing g/L: $(NH_4)_2SO_4$-3, KCl-1, $MgSO_4 \cdot 7H_2O$-0.5, KH_2PO_4-0.5, and $FeSO_4 \cdot 7H_2O$-44.2. The pH of this medium was adjusted to 1.5 with dilute sulphuric acid. The bacterial growth was assessed from the appearance of brown colour in the 9 K medium due to the formation of ferric iron. The strain was screened for its ability to leach nickel and cobalt from its ore at low pH conditions, i.e., 1.5-2.5.

Table 1. Chemical analysis of different types of lateritic ore

Type of ore	Percentage (%)					
	Ni	Co	Fe	Cr	Mn	(AI)
Raw ore	0.62	0.032	46.86	4.14	0.37	8.8
Roasted ore (300 °C)	0.67	0.037	55.85	4.18	0.42	7.4
Palletized activated ore 400 °C	0.76	0.04	55.87	4.20	0.50	7.9
Palletized activated ore 600 °C	0.77	0.042	55.88	4.21	0.52	7.8

Note: Ni indicates Nickel, Co-Cobalt, Fe-Iron, Cr-Chromium, Mn-Manganese and AI-Acid Insoluble.

5. Leaching Experiments

5-1. Adaptation Studies

Adaptation was done for obtaining efficient strains for increased extraction of nickel from laterites. Before the leaching experiments were performed, the consortium was initially adapted to nickel at a concentration from 0.25 g/L till 1 g/L to improve the tolerance of the strain.

The adaptation experiments were carried out with mixed consortium of *Acidithiobacillus* sp. and adapted to a concentration of 1 g/L nickel. Another experiment was carried out with the mixed consortium which was not adapted to the different nickel concentration. Before the experiments were carried out in bioreactor, optimizations of the parameters were done in shake flask and this optimum condition was taken for these bioreactor experiments. The experiments were carried out at 35 °C in 250 ml conical flasks in 90 ml of 9 K^+ media each containing 10% (w/v) of different forms of lateritic nickel ore. The redox potential (Eh) was also measured. For experimentation 10 ml of aliquots of late log phase cultures containing 2.5×10^8 cells/ml of adapted and un-adapted were transferred separately to each flask containing the ore. The pH of the solution was adjusted at 1.5 and the flasks were agitated continuously in a rotary shaker at 150 rpm for an incubation period of 30 days. Samples were taken at regular intervals for analyses of nickel and cobalt by Perkin Elmer Atomic Absorption Spectrophotometer (AAS) after suitable dilutions in distilled water.

5-2. Bioreactor Studies

Five sets of experiments were further set up in bioreactor with the pulp density of 10% (w/v) using raw, roasted (300 °C), and roasted ore presoaked in dilute sulphuric acid and palletized pretreated ore (roasted at 400 °C and 600 °C). Leaching experiments in bioreactor were carried out using the adapted cultures of mesophilic acidophiles bacterial consortium because adapted cultures gave better nickel and cobalt recovery than the laboratory cultures.

5-2-1. Bioreactor Description

Batch experiments were conducted in 40 L single stage stainless steel (SS-316) bioreactor equipped with stirrer and air sparger. The diagram of the bioreactor is shown in Fig. 1. The bioreactor is designed with a flat top and hemispherical bottom. The bioreactor plant is designed to handle a maximum solid-liquid ratio of 40%. The pulps are stirred with a mechanical stirrer having air dispersing blades rotating at variable speeds and baffles in the reactor. The hemispherical part of bioreactor consists of stainless steel inlet for continuous feeding and a stainless steel raining chamber with outlet pipe with a variable speed regulator. The airflow rate was controlled by an airflow meter and agitation speed by a tachometer. An electronic control panel attached to the bioreactor for monitoring temperature, pH and Eh.

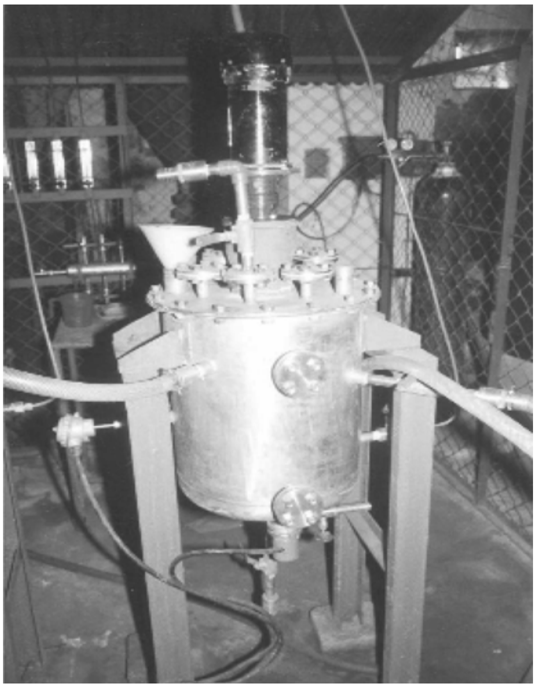

Fig. 1. 40 L capacity bioreactor (Stainless Steel-SS316).

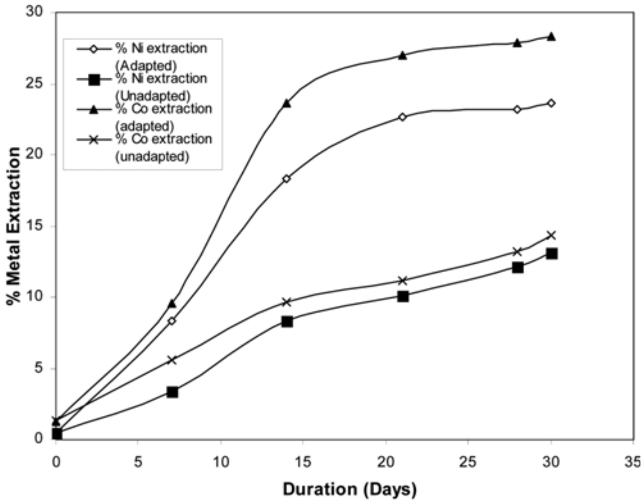

Fig. 2. Effect of pre-adaptation of *Acidithiobacillus* sp. to 1 g nickel/ liter on nickel and cobalt extraction at 10% pulp density (Conditions: Ore-Raw lateritic ore, pH-1.5, Speed-150 rpm, Temperature-35 °C, Inoculum size-10%, Duration-30 Days).

5-2-2. Biological Leaching Experiments

First batch of experiment was conducted in 40 L bioreactor with raw ore at 10% (w/v) pulp density, 10% (v/v) inoculum concentration in 9 K^+ medium. The experiment was carried out at 35 °C with pH 1.5; the speed was maintained at 400-500 rpm with the airflow rate provided at 2-3 L/min. There were no significant extraction of nickel and cobalt observed; thereafter the experiments were terminated after a period of 17 days. The slurry samples were taken from bioreactor at regular intervals and it was allowed to settle down. After about 30 minutes the upper clear part of the solution was filtered and suitable dilutions was made with the help of distilled water. Then it was taken for analysis of nickel and cobalt by AAS (Atomic Absorption Spectrophotometer).

Second batch operation was carried out with roasted (300 °C) lateritic nickel ore and rest all the conditions were same as described in the first set of bioreactor experiments. The process was carried out for duration of 13 days until there was no further extraction of nickel from the ore. This was followed by yet a third batch mode experiment in bioreactor using roasted ore, where the ore was presoaked in dilute sulphuric acid for 24 hours. The experimental conditions were similar to the previous set of experiments. After duration of 13 days there was no significant extraction of nickel and cobalt so the bioreactor experiment was terminated.

Fourth and fifth batch experiment was carried out using palletized pretreated lateritic nickel ore which was roasted at 400 °C and 600 °C. Rest conditions were similar to the conditions mentioned in other 3 sets of experiments. The process was carried out for duration of 31 days till there is no further extraction of nickel and cobalt from the ore.

Simultaneously control experiments were also performed for each set experiments of lateritic ore with addition of saturated solution of 10 ml $HgCl_2$ as bactericide. The experimental conditions were same for all the sets except the addition of microorganisms.

RESULTS AND DISCUSSION

1. Shake Flask Studies

Fig. 2, summarizes leaching results in shake flask studies using the laboratory stock cultures and adapted (adapted to 1 g nickel/L) microbial cultures at 10% (w/v) pulp density (raw nickel ore) with 10% inoculum (v/v) of initial bacterial concentration 2.5×10^8 cells/ml for a duration of 30 days. The pH was adjusted to 1.5. The pH was adjusted everyday with 1 N sulphuric acid. The Eh measured in the first day was 540 and in the initial day of experiments (2nd to 20th day) the pH and Eh was increased upto i.e. 1.86 and 780 mv. Then towards the 30th day the pH and Eh was decreased to 1.32 and 432 mv. It can be seen that the adapted culture yield more nickel and cobalt than the laboratory un-adapted culture. The nickel and cobalt extraction percentage for adapted culture were 23.61 and 28.34% and for un-adapted culture 13.06% nickel and 14.36% cobalt respectively (Fig. 2). The control experiments carried out with 1 g nickel/L showed 3.16 and 3.98% nickel and cobalt and another set of control experiment carried out without nickel showed 3.06 and 3.35% respectively.

A comparative study was made to determine the effect of pre adaptation of the mixed consortium of *Acidithiobacillus* sp. to ore on the metal solubilisation. This supports previous reports that adaptation of microorganisms is helpful [5]. Further experiments were, therefore, performed with adapted culture.

2. Bioreactor Studies

Nickel and cobalt recovery was observed maximum in case of palletized pretreated ore at 600 °C whereas the palletized ore at 400 °C shows less recovery (Fig. 6 and 7) after a period of 31 days. But in the case of batch experiments with roasted ore presoaked in dilute sulphuric acid the maximum recovery of nickel and cobalt observed was (29.1% and 63.6% respectively) and the least was observed in case of raw nickel ore (Fig. 5). The pH variation was seen from 1.3

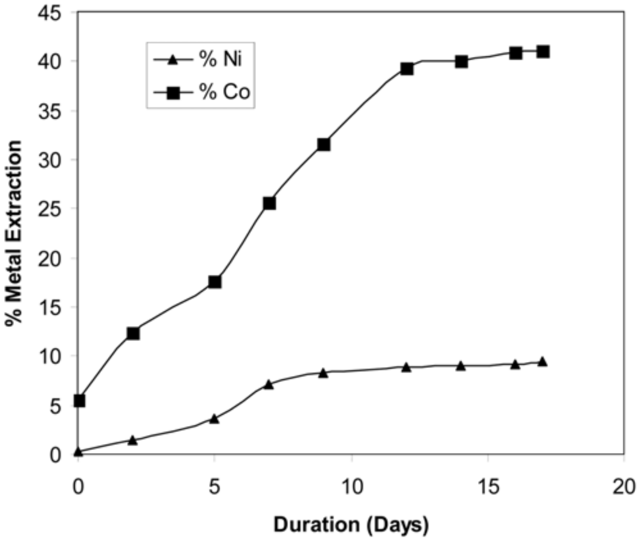

Fig. 3. Effect of duration on extraction of nickel and cobalt with raw ore in 40 L bioreactor (Conditions: PD=10%, Duration=17 days, pH=1.5, Bacterial concentration=2.5×10^8 cells/ml, Temperature=35 °C, Agitatation-400-500 rpm, Aeration-2-3 L/min).

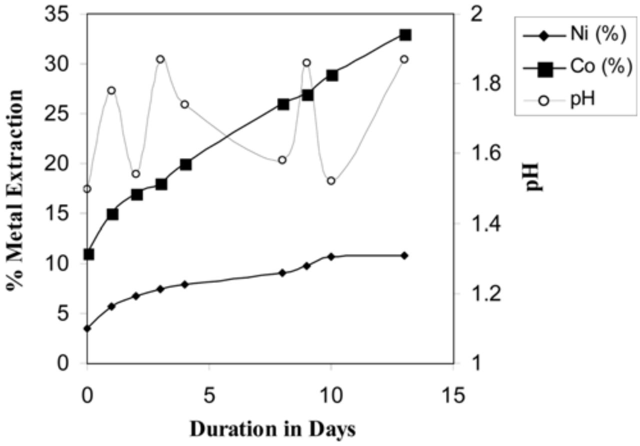

Fig. 4. Effect of duration on extraction of nickel and cobalt in 40 L bioreactor using roasted ore (300 °C) (Conditions: Pulp Density=10%, Duration=13 days, pH=1.5, Bacterial concentration=2.5×10^8 cells/ml, Temperature=35 °C, Agitation-400-500 rpm, Aeration-2-3 L/min).

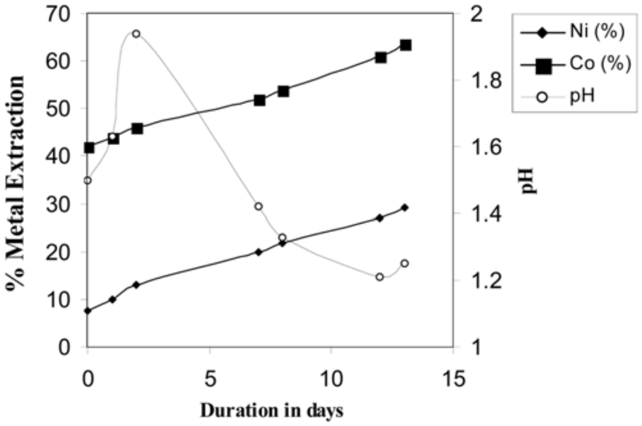

Fig. 5. Effect of soaking on extraction of nickel and cobalt in dilute H_2SO_4 with roasted ore (300 °C) (Conditions: Pulp Density=10%, Duration=13 days, pH=1.5, Bacterial concentration=2.5×10^8 cells/ml, Temperature=35 °C, Agitation-400-500 rpm, Aeration-2-3 L/min).

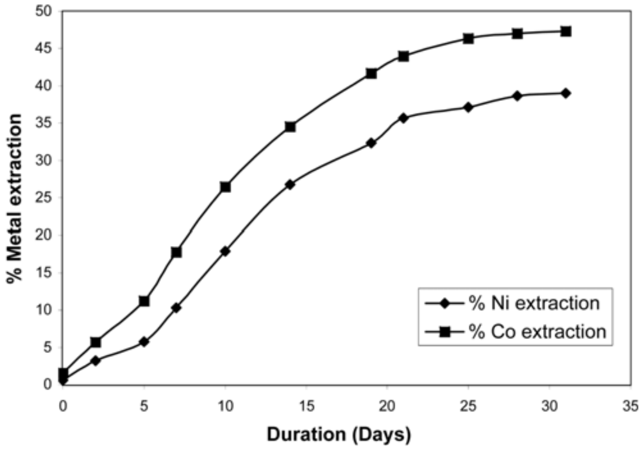

Fig. 6. Effect of palletized activated ore (roasted at 400 °C) on nickel and cobalt extraction in 40 L bioreactor (Conditions: Pulp Density=10%, Duration=31 days, pH=1.5, Bacterial concentration=2.5×10^8 cells/ml, Temperature=35 °C, Agitation-400-500 rpm, Aeration-2-3 L/min).

to 1.9 in Fig. 4 and 5 and the Eh was increasing from 405-598 mv and towards the end of the experiments it was decreasing to around 385 mv. This indicates that the microorganism has slows down its metabolic activity.

Fig. 3, shows the extraction of nickel and cobalt in the leaching experiments carried out in bioreactor in batch mode with raw ore using the adapted culture was 9.47% and 41.12% respectively after incubation period of 17 days. There was no significant recovery of nickel from raw ore so, for better recovery experiments were again conducted in bioreactor using roasted ore with similar conditions as the previous set. Still there was no increase in the recovery of nickel and cobalt (10.8% and 32.8% respectively) after a period of 13 days (Fig. 4). In these laterites, nickel is present in the form of Ni-O in the goethite matrix which is a hydrated iron oxide (α-FeOOH). So, it may be assumed that the nickel in the laterite ores (raw) are very tightly entangled in the lattice and therefore nickel is not easily dissolved and less susceptible to attack by the microorganisms. The whole nickel-bearing goethite matrix has to be dissolved to extract all the nickel present in the ore. Hence we observe a poorest extraction of nickel in raw ore.

The bioreactor experiments conducted with palletized pretreated ore at 600 °C exhibits maximum nickel and cobalt recovery after a period of 31 days i.e. 77.23 and 73.22% (Fig. 7) respectively. Whereas the nickel recovery using pretreated palletized ore at 400 °C shows lesser recovery of nickel and cobalt i.e. 39.01 and 47.34% respectively (Fig. 6). The pH of the experiments with palletized pretreated ore (600 °C) was fluctuating between 1.5-2.45 within 20 days and after that the pH was decreased in the range of 1.6-1.75. The

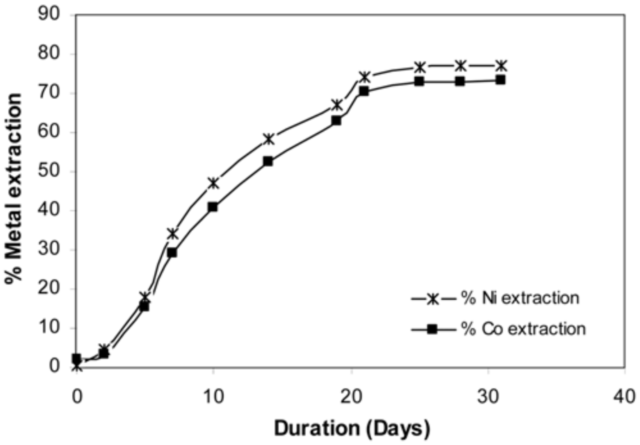

Fig. 7. Effect of palletized activated ore (roasted at 600 ºC) on nickel and cobalt extraction in 40 L bioreactor (Conditions: Pulp Density=10%, Duration=31 days, pH=1.5, Bacterial concentration=2.5×10^8 cells/ml, Temperature=35 ºC, Agitation-400-500 rpm, Aeration-2-3 L/min).

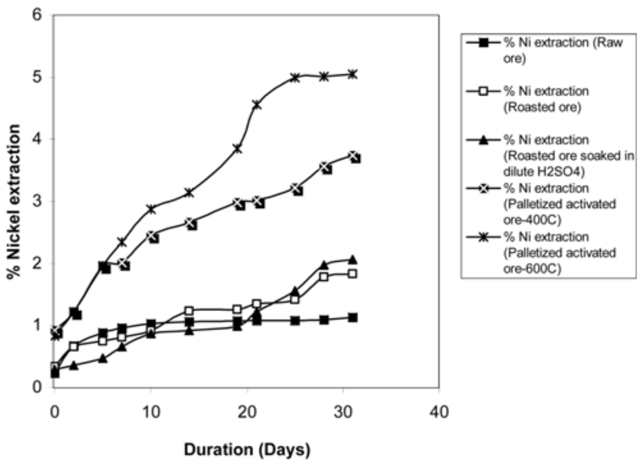

Fig. 8. Effect of different types of lateritic nickel ore on nickel extraction in 40 L bioreactor without microorganisms (Conditions: Pulp Density=10%, Duration=31 days, pH=1.5, Temperature=35 ºC, Agitation-400-500 rpm, Aeration-2-3 L/min).

same condition was also observed in case of pretreated ore (400 ºC) first the pH was increased in the range of 1.5-1.96 upto 15th day and then the pH was decreased to 1.45. The Eh in the first day of the experiment both with pretreated ore at 400 ºC and 600 ºC was around 450 mv and it was increased to about 740-809 mv in the first 20 days. Then after 20th day the Eh starts decreasing to about 420 thereby indicate that the microorganism has attended a steady phase of growth. Therefore it was observed that there was no significant recovery of nickel and cobalt towards the 31st day due to the jarosite precipitation and microorganisms slows down its metabolism. In the control set of experiments percentage of nickel recovery with raw, roasted and roasted ore pre-soaked in dilute sulphuric acid was 1.13, 1.83 and 2.06 respectively. In case of palletized pretreated ore (control) at 400 ºC and 600 ºC nickel recovery was 3.74 and 5.05% (Fig. 8). The cobalt recovery observed in case of the control exper-

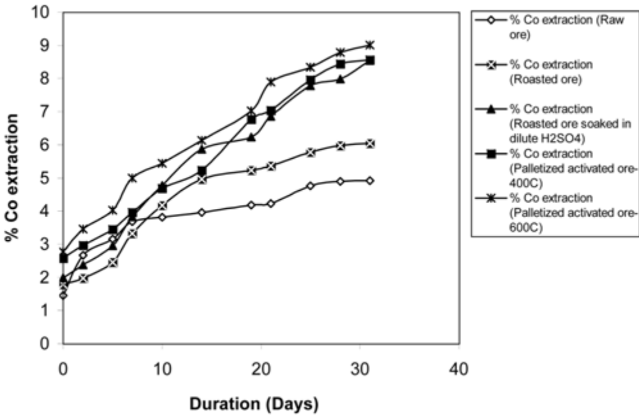

Fig. 9. Effect of different types of lateritic nickel ore on cobalt extraction in 40 L bioreactor without microorganisms (Conditions: Pulp Density=10%, Duration=31 days, pH=1.5, Temperature=35 ºC, Agitation-400-500 rpm, Aeration-2-3 L/min).

iments with raw, roasted, roasted ore presoaked in sulphuric acid and pretreated ore at 400 ºC and 600 ºC were 4.92, 6.04, 8.54, 8.56 and 9.01% respectively (Fig. 9). The finding clearly shows that microorganisms play a major role in dissolution of nickel and cobalt from the goethite matrix.

Lowest recovery is seen in case of raw lateritic nickel ore because goethite is the main nickel bearing mineral phase and cobalt is present with the manganese. Goethite is stable at room temperature and dehydrates to hematite only at 130 ºC [26,27]. The roasted ore presoaked with acid showed slightly higher recovery and it may be assumed that the acid helps in partially dissolving the goethite matrix thereby releasing the nickel. It is observed that palletized pretreated ore (600 ºC) is optimum for nickel and cobalt recovery because the ore undergoes physical and mineralogical characteristic change. This change helps in converting the complex association of goethite to hematite structures and during dehydration nickel becomes unstable and is more susceptible to attack which accelerates the dissolution of nickel.

The pretreatment of ore at different temperatures helps in the conversion of goethite (FeOOH) into hematite (Fe_2O_3). The probable mechanism behind the leaching of the lateritic ores using *Acidithiobacillus* spp. is that the nickel is present in the form of NiO and reacts with sulphuric acid provided in the medium and converts to nickel sulphate and water. The sulphuric acid when reacts with the hematite (Fe_2O_3) converts to ferric sulphate ($Fe_2(SO_4)_3$) and water. Simultaneously, NiO reacts with water and ferric sulphate (produced by the oxidation of ferrous ions by *Acidithiobacillus*) and this $Fe_2(SO_4)_3$ hydrolyses to form ferric hydroxide (jarosite) and nickel sulphate which is water soluble. This helps in the enhancement of leaching percentage of the pretreated ores.

This study gives an overview that the nickel and cobalt minerals must be converted to compounds, which can be easily solubilized by the leaching media and so require liberating nickel and cobalt from the goethite matrix before the leaching reagent can directly react with nickel and cobalt in laterite ores.

3. Mineralogy

The leaching ability of the mixed mesophilic acidophiles con-

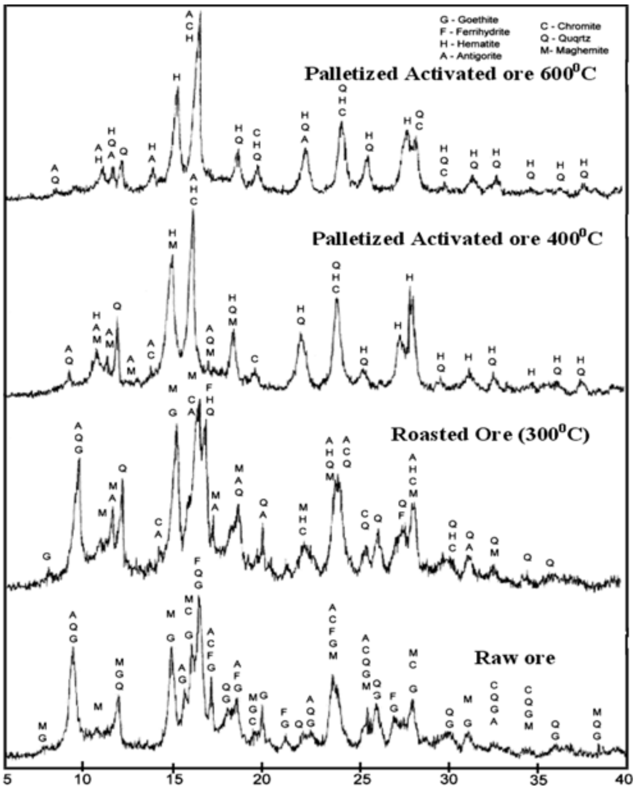

Fig. 10. X-ray Diffractometer analysis of raw, roasted (300 °C) and pretreated ore (400 and 600 °C) (G-Goethite, F-Ferrihydrite, H-Hematite, A-Antigorite, C-Chromite, Q-Quartz and M-Maghemite).

sortium towards raw, roasted (300 °C) and palletized pretreated ore at 400 °C and 600 °C were studied. The difficulties in the amenability of these ores towards biological leaching using the raw lateritic nickel ore were further supported by XRD (X-ray Diffractometer) data. To establish the mineralogical contribution to the variation in recovery, the raw, roasted (300 °C) and the pretreated palletized ore at 400 °C and 600 °C were examined by optical microscopy and synchrotron X-ray diffraction. Laterite is a highly weathered material in which the main nickel-bearing mineral is the hydrated iron oxide or goethite (FeOOH). In this lateritic nickel ore it has been assumed that nickel together with aluminium, and chromium is incorporated in the goethite matrix in solid solution with iron, (Fe,Ni) $O(OH)\cdot nH_2O$ [27,28]. The synchrotron X-ray Diffraction of the raw, roasted and pretreated ore of nickel laterite is shown in Fig. 10. The mineral phases as observed from XRD (X-ray Diffractometer) patterns in Fig. 10 reveals the presence of goethite, maghemite and quartz as major minerals and minor are antigorite and chromite and trace is ferrihydrite in raw ore. In roasted ore (300 °C) quartz, antigorite and maghemite are the major mineral phase, minor are chromite and hematite and traces of goethite and ferrihydrite are found. In pretreated ore at 400 °C the major minerals found are hematite and quartz, minor are antigorite and maghemite and chromite is present as trace mineral phases. Palletized pretreated ore (600 °C) reveals the presence of hematite and quartz as major mineral phase and antigorite and chromite are minor elements. Goethite is stable at room temperature and dehydrates to hematite only at 130 °C [24, 25]. When roasting is done at high temperatures goethite (FeOOH) gets converted to hematite (Fe_2O_3) and nickel may become exposed in micro-pores and cracks developed in the particles, being more susceptible to leaching by the microorganisms [16]. It may be possible that at high temperatures nickel becomes unstable thereby more susceptible to attack by the microorganism and accelerates the dissolution. The goethite peaks disappears in the roasted ore. But in the palletized pretreated ore there are no goethite peaks instead the peaks are dominant with hematite. In the raw ore the abundance of minerals are as follows: goethite>quartz>maghemite>antigorite/chromite>ferrihydrites. The abundance of minerals in the roasted ore (300 °C) are quartz>antigorite>maghemite>chromite>hematite>goethite>ferrihydrites, and pretreated ore (400 °C) are: hematite>quartz >antigorite>maghemite>chromite. In the pretreated ore (600 °C) abundance of minerals follows: hematite>quartz>antigorite>chromite.

CONCLUSIONS

From the above described investigation it is very clear that the mixed consortium of mesophilic acidophiles predominantly *Acidithiobacillus* spp. were used for bioleaching of lateritic nickel ore from the ultra basic belt of Orissa, which is a major nickel laterite deposit. The pre-adaptation experiment carried out at 10% pulp density shows that adapted culture yielded more nickel and cobalt (23.61 and 28.34%) than the un-adapted culture i.e. 13.06% nickel and 14.36%. Nickel and cobalt recovery was maximum with palletized pretreated ore at 600 °C after a period of 31 days i.e. 77.23 and 73.22% using *Acidithiobacillus* sp. Least recovery was observed in case of raw lateritic nickel ore after a period of 17 days 9.47% and 41.12%. Biological leaching of roasted lateritic nickel ore at 10% pulp density using the adapted culture resulted in 10.8% nickel and 32.8% cobalt solubilisation after 13 days. The same material pre-soaked in dilute sulphuric acid followed by leaching in bioreactor results an increase in nickel and cobalt extraction to 29.1% and 63.6% respectively. Thus pre treatment could improve leaching rate because this acid is found to be little more effective in dehydrating goethite to hematite so, slightly higher recovery was observed in case of soaked roasted ore. Leaching efficiency was better in case of pretreated and roasted ore as compared with raw lateritic nickel ore. This may be due to the fact that roasting at high temperature around 360 °C breaks the bond between nickel oxide which is present in the goethite matrix and in the process goethite gets converted to hematite which makes the leaching better.

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