Assessing the effectiveness of a biological recovery of nickel for tailing dumps management

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Abstract

The mobilization of nickel from sulphide minerals using sulfuric acid and heterotrophic microorganism (*Bacillus subtilis*) was independently examined. The influences of parameters such as the concentration of acid and bacteria as well as reaction time were considered. Results of the monod-type kinetic study showed faster recovery of nickel from tailings (20 ppm/h) than from ore (8.07 ppm/h) by biological mobilization and similar trend with sulfuric acid.

Key words Nickel mobilization, *Bacillus subtilis*, sulfuric acid, tailings, ore

1. Introduction

Dissolution of sulphide minerals using reagents such as sulfuric acid is frequently practiced in industry for the recovery of metals. This process is carried out at a high temperature to promote the dissolution, and toxic byproducts such as SO_2 are also released (Pecina et al., 2007). High cost, harsh operating conditions and environmental pollution are further negative aspects associated with this approach (Rubio and Frutos, 2002). An alternative method using autotrophic microorganisms such as

Acidothiobacillus and *Leptospirillum ferrooxidans* for metal recovery is difficult to operate and pose problem of water effluent acidification (Das et al., 1999).

Heterotrophic microorganisms that operate at neutral pH can mobilize the metal from a sulphide mineral by complexation using biodegradable chelating agents they produce (Brandl and Faramarzi, 2006). This approach provides the advantage of reducing steps in the recovery process and also ensures safer operating conditions as well as minimizing release of pollutants. Many studies have been done on the kinetics of bioleaching while generally involving autotrophic microorganisms and have primarily focused on the impact of particle sizes (shrinking core kinetics) on the reaction (Lizama, 2003). In this study we report on how to effectively use a heterotrophic microorganism (*B. subtilis*) to substitute the conventional method for the potential recovery of residual nickel (tailing dumps management).

2. Methodology

2.1. Preparation and characterization of mineral

Sulfide ore and tailing dumps obtained from the Inkhomatsi Mining Company SA, were crushed and screened through a sieve of 75 µm. The powder form of the minerals (<75 µm grain size) was then characterized using the XRD and nickel content extracted by aqua regia and measured with ICP-OES. Mining ore contained more sulphide and iron compounds than tailings. The nickel content was 0.15% in the tailings and 0.6% in the ore.

2.2. Biological experiment

2.2.1. Nickel tolerance by *Bacillus subtilis*

Bacteria were exposed to various concentrations of nickel (0 ppm; 30 ppm; 50 ppm and 100 ppm) in nutrient broth, incubatd at 37°C overnight and the growth monitored as absorbance at 600 nm using a UV spectrophotometer (Helios Epsilon-USA).

2.2.2. Metal mobilization

Bacillus subtilis was inoculated in the nutrient broth media and incubated at 37^{o}C in the shaking incubator for overnight growth. The culture was then centrifuged at 15000 rpm for 15 min and the pellet was washed with distilled water. A defined mass of wet cells (0.1 g, 0.2 g and 0.4 g) in centrifuge tubes were suspended in 100 ml distilled water and dispensed into a 250 ml Erlenmeyer containing 1 g of mineral (ore or tailings). The mixture was incubated at 37^{o}C in a shaking incubator (150 rpm) and 5 ml of the solution was collected at six interval periods (2h, 4h, 6h, 20h, 22h and 24h) for analysis with ICP-OES.

2.3. Conventional leaching of nickel

Prepared solutions of sulfuric acid (0.5M, 1M and 1.5M) were poured (100 ml) into a 250 ml Erlenmeyer containing 1 g of mineral. The mixture was incubated as above and filtered with Whatman paper prior to ICP-OES analysis.

3. Results and discussion

3.1. Effect of nickel on Bacillus subtilis growth

Results showed that low concentration of nickel relatively increase bacteria growth while higher concentrations inhibit their growth.

3.2. Biological mobilization of nickel from tailings dumps and mining ore

Similar patterns were observed during nickel mobilization from ore and tailings as a positive correlation between bacteria biomass and the amount of mobilized nickel (Figure 1) was recorded.

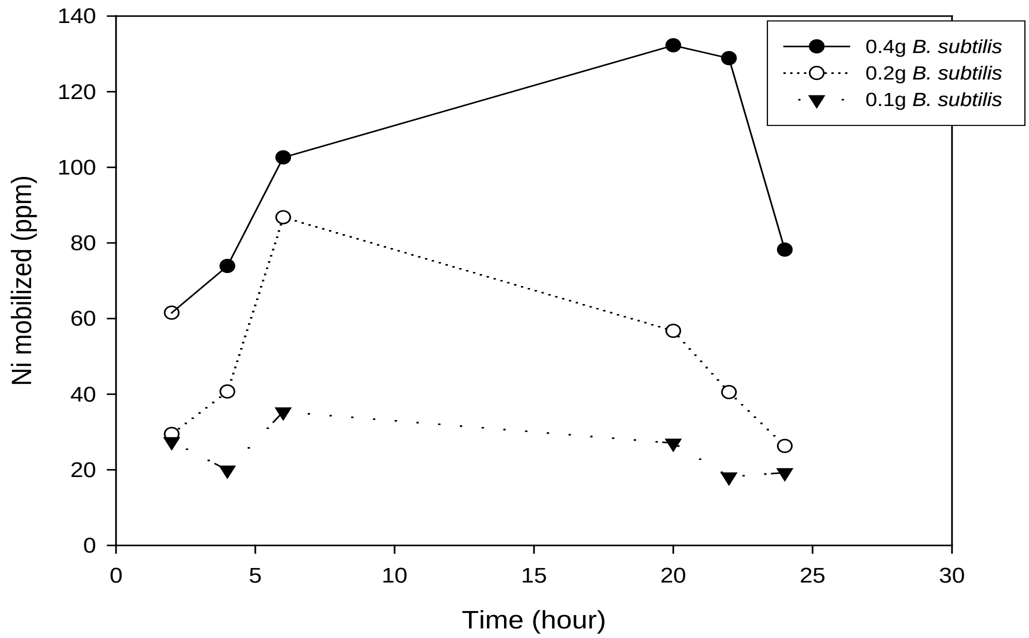

Fig. 1. Biological mobilization of nickel from ore as a function of time and biomass concentration

The plots in both Figures show two phases, that can be identified as the "active phase" and the "latent phase". In the first phase the progressive mobilization of nickel could be ascribed to the normal activity of bacteria producing chelating agents that are responsible for the mobilization of nickel. In the latent phase, higher concentrations of nickel contribute to the inhibition of the bacteria (as demonstrated in figure 1) affecting their physiological activities. Sorption of the nickel in solution by bacteria, happening simultaneously with the inhibition, will ultimately lead to the reduction of the amount of mobilized nickel in solution. According to Nies (1999) high concentrations of metal cations affect bacterial growth by inhibiting the enzymatic activities and physiological functions; a phenomenon, which we have previously reported (Fosso-Kankeu et al., 2010). The kinetic defining the rate of nickel mobilization might therefore be only applicable to the active phase of the plot. In fact, nickel mobilization in both figures directly depends on the bacterial concentration, and both parameters can therefore be related on the basis of a monod-type kinetic study. The mobilization rate can be given by the equation deriving from the model proposed by Michaelis-Menten:

$$V_0 = \frac{V_{\mathrm{max}}[\mathrm{S}]}{K_{\mathrm{m}} + [\mathrm{S}]}$$

Where V_0 is the mobilization rate of nickel, V_{max} is the maximum nickel mobilization rate; K_m is the Michaelis constant and [S] is the biomass of bacteria.

The intercept of the Line weaver-Burk plots was used for determination of the maximum mobilization rate of nickel from the tailings (20 ppm/h) and from the ore (8.07 ppm/h). It was found that nickel mobilization from the tailings occurred at a faster speed. Easy diffusion of solvent in tailings which are less complex, promotes effective action of bacteria.

3.4. Nickel extraction from ore and tailings with sulfuric acid

Sulfuric acid extracted more nickel from tailings than from ore, but increase of acid concentration did not significantly improve the recovery rate. Complex polysulfides and elemental sulfur in mining ore form extra layers that could hinder the diffusion of solvent during dissolution (Wen-qing et al., 2008).

In our previous studies (unpublished), uninterrupted bioreaction over 24 hours allows to mobilize 28.5% of nickel from tailings, which represents better performance over conventional method. This result enlightens about the capability of *B. subtilis* to mobilize metal.

4. Conclusion

The use of heterotrophic microorganisms, for the mobilization of nickel from minerals appears to be feasible and comparable to the acidic method in terms of the amount of nickel mobilized with the further advantage of being ecofriendly. There is certainly a concern about the relatively low speed of metal mobilization and the possible inhibition of bacteria by a high concentration of metal. Molecular modification of bacteria and/or improvement of the protocol of operation could provide a satisfactory solution. This study has shown the use of *Bacillus subtilis* can provide an environmentally safe, cheap and prolific method for the management of tailing dumps that are abandoned.

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