

Bioremediation of Mining Tailings with Simultaneous Nickel and Sulfur Recovery

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Pyrrhotite mineral (Fe_7S_8) tailings from nickel mining operations in northern Ontario, Canada amount to more than 100 million metric tonnes (by dry weight). This iron sulfide waste is an acid-generating waste which if left stored in the open, can mobilize many regulated elements contained therein and contaminate groundwater. Currently, the tailings are stored under the cover of water or stacked in the open. Any runoff waters are collected and neutralised whereas different types of oxygen barriers are applied. Earlier attempts by Inco (now Vale) and Falconbridge (now Glencore) to actively treat these pyrrhotite tailings via high-temperature (pyrometallurgical) processes have been unsuccessful due to high costs and release of SO_2 . Bioleaching technology offers an opportunity for cheaper and more environmentally friendly treatment of the tailings for remediation and recovery of value products, such as nickel and sulfur. Although heap bioleaching is a preferred approach due to its low operating cost and ease of scale-up (Brierley and Brierley, 2013), the very high sulfur content of tailings and the consequent high exothermicity of pyrrhotite leaching prevent heap bioleaching from being a viable option. An agitated bioreactor approach comes with process control options to maintain reactor temperature, and the oxidative state of the sulfur at its elemental form (S^0) as opposed to sulfate (Johnson, D. B., 2000). The reason for aiming at producing elemental sulfur is to reduce sulfuric acid production and gypsum formation. A clean separation and recovery of elemental sulfur will create an additional revenue stream. The nickel contained in the tailings (~ 0.7 wt%) is the main source of value recovery. The total value was estimated at 100 USD/MT assuming 70% nickel recovery (Peek, et al, 2010). The process remediates and generates revenue streams that offset the processing costs.

Most microbial strains used in bio-oxidation oxidize iron to ferric and sulfur to sulfate. Many of those strains were found in the local microbial community at the Sudbury mining site and they were adapted to serve in a bioleaching process. We have characterized the pyrrhotite tailings and have extensively studied the abiotic ferric leaching kinetics. We have also adapted the indigenous microbial culture collected from the mining sites to a 10% w/v upgraded Po tailings and found that the main iron and sulfur oxidizer was *Acidithiobacillus ferrooxidans* achieving 100% dissolution of the solids. However, most of the sulfur ($>97\%$) was also oxidized to sulfate.

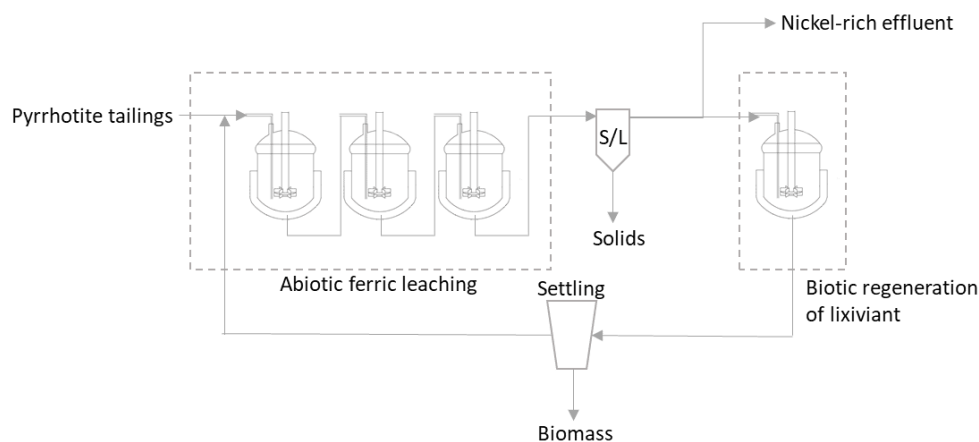


Figure 1. Process flow diagram of the two-step process to treat pyrrhotite tailings.

To study the above issue more systematically while also exploring the prospect of developing a commercial process, we proposed a two-step process (Figure 1) with 1) an abiotic ferric sulfate leaching of pyrrhotite to leach the tailings, dissolve nickel and make elemental sulfur and 2) a microbially-assisted regeneration of lixiviant (ferric ion). In doing so we avoid microbial oxidation of S^0 , while we biocatalyse the regeneration of Fe^{3+} from Fe^{2+} . A reliable model is needed to optimize this two-step process. Although we studied the optimal conditions for the abiotic leaching of pyrrhotite tailings at high solids loading (up to 20 wt%), but the biotic oxidation of ferrous ion and subsequent integration of the two steps still needs investigation. The present communication focuses on the development and analysis of a steady-state model based on previous work and data obtained in our group at the U of T.

The Monod equation (Eq.1) is an empirical rate law equation that was developed in 1949 by Monod which describes microbial growth kinetics. The specific growth rate of microbes, μ (h^{-1}) is a function of the maximum specific growth rate of microbes, μ_{max} (h^{-1}), the limiting substrate concentration, $[S]$ (g/L), and a saturation constant, K_S' (g/L).

$$\mu = \frac{\mu_{max}[S]}{[S] + K_S'} \quad \text{Eq.1}$$

A modified Monod equation can be derived based on a ferric inhibition mechanism (Valdés et al., 2008) as per Equation 2.

$$\mu = \frac{[S]\mu_{max}}{[S] + K_S \left(1 + \frac{[P]}{K_P}\right)} \quad \text{Eq.2}$$

The mass balances of the substrate (Eq. 3) and the cell biomass (Eq. 4) at steady state are shown below:

$$D[S_0] - D[S] - \left(\frac{\mu[X]}{Y_0} + r_{abiotic\ oxidation}\right) = 0 \quad \text{Eq.3}$$

$$-D[X] + \mu[X] - r_{cell\ decay} = 0 \quad \text{Eq.4}$$

where D (h^{-1}) is the reactor dilution rate and Y_0 ((g cells)/(g Fe^{2+})) is the apparent yield coefficient. The two rate equations (Eq. 1 and Eq. 2) can be substituted into the above steady-state mass balances and the steady-state solutions can be derived algebraically.

The model was tested against experimental measurements in a continuous aerated bioreactor. It was shown that at a constant total Fe concentration (which is the case in a continuous bioreactor at a steady state), the two rate laws are mathematically equivalent, with one having an additional parameter. The classic Monod equation was found adequate to model the continuous bio-catalysis of Fe(II) to Fe(III) oxidation with atmospheric oxygen under an acidic pH of 1.5.

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