Available online at www.elixirpublishers.com (Elixir International Journal)

Renewable Energy

Elixir Renewable Energy 102 (2017) 44187-44189

ISSN: 2229-712X

Bioleaching of Ni from Industrial Sludge

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ARTICLE INFO

Article history:

Received: 23 December 2016;

Accepted: 5 January 2017;

Published:10 January 2017;

Keywords

Bioleaching,

Nickel (Ni),

Rate constant,

Acidithiobacillus ferrooxidans.

ABSTRACT

Electroplating sludge contains huge of Ni. Bioleaching is found to be the best method to remove heavy metals. But, the temperature play vital role. In the present study, the influence of temperatures on the removal of Ni from electroplating sludge was investigated using bacteria, *Acidithiobacillus ferrooxidans*. Results showed that the maximum of 90.5% Ni was removed from the sludge under the temperature maintained at 37 °C. It was found that the rate constants obtained for Ni bioleaching at 37 °C was high.

Introduction

Almost all the sludge that is generated in the industries is disposed of in open fields due to lack of appropriate disposal facilities [1]. In order to get rid of various health hazards caused due to this electroplating sludge disposal, it is necessary to give more importance for Ni removal from the sludge.

Several studies showed that, there are different methods available for removal of metals from sludge. Though, they have been widely applied in practice, they also possess several limitations such as high cost and low efficiency [2]. Alternatively, biological method that employs microbes as the leaching catalyst for removing metals which known as bioleaching. It is proven to be more economical and environmentally acceptable [3]. Bioleaching processes are based on the sulphur oxidation by chemolithotropic bacteria [4]. The intensively used microorganism in the bioleaching processes is seemed to be A. ferrooxidans [5]. They obtain energy by oxidizing elemental sulphur (S^0) [6]. In this mechanism, S^o is oxidized first to sulfuric acid by the action of bacteria and then sulfuric acid aids the dissolution of metals [6]: There are numerous works have been carried out on different parameters on sludge bioleaching, but only a few demonstrate bioleaching kinetics [7]. The aim of the present study is to evaluate the influence of temperature in the bioleaching of Ni from electro plating sludge and study the rate kinetics of leaching process using the procured culture A. ferrooxidans.

Materials and Methods

Sludge sample collection and characterization

Sludge has been collected from a electroplating industry located at Kumarapalayam, Chennai. Samples were collected in polypropylene bottles and the sludge was air-dried at room temperature overnight. Metal content in the sludge were determined after acid digestion (HNO_3/H_2O_2). The dissolved metal concentration in the sludge was determined after membrane filtration and quantified using atomic absorption spectrometer (AA200 model; PerkinElmer). Available phosphorus in the sludge was determined using micro-vanadate-molybdate method after extracting the total amount with 0.5 M sodium bicarbonate using spectrophotometry. Using the flame photometer (CL378 model; Elico; India), concentration of sodium, potassium and calcium were determined. Soluble sulfate estimation was done by the barium sulfate precipitation method using UV-visible spectrophotometer (U2900 model; Hitachi; Japan).

Microorganism and Media:

Strain, A. ferroxidans (NCIM 5371) was procured from National Collection for Industrial Microorganism, Pune. They were grown in 9K synthetic medium with composition: $(NH_4)_2SO_4$(3 g /L), $MgSO_4.7H_2O$ (0.5 g /L), K_2HPO_4 (0.1 g /L), $Ca(CO_3)_2$ (0.01 g /L), S^o (10 g/L), and KCl (0.1 g/L). The media pH was adjusted to 3 using 1N H_2SO_4 to stimulate the bacterial growth. It was cultivated in an orbital shaker at 150 rpm for two weeks. They were routinely sub cultured every 10 days for further activation.

Bioleaching experiments

Bioleaching experiments were carried out in 250 mL capacity Erlenmeyer flasks with 100 mL working volume and supplemented with 5g of sludge. The flasks were inoculated with 10% (v/v) bacterial culture and the flasks were incubated at different temperatures such as 27, 30, 33, 37, 40 °C. The initial pH was set to 3 for the bioleaching experiments. The flasks were maintained at different temperatures and rotated at 150 rpm. The changes in the media pH and ORP were monitored every two days during the bioleaching course. The 5 mL of samples were drawn from the flasks to determine the concentration of solubilized Ni from the sludge. Solubilized Ni was determined using UV-Visible Spectrophotometer (U2900 model; Hitachi; Japan). Metal bioleaching efficiency of Ni, denoted by η (%), was calculated using the following equation:

$$\eta\% = \left(\frac{Ni_0 - Ni_{soln}}{Ni_T}\right) \times 100 \qquad \text{------------------ (1)}$$

where, Ni_0 and Ni_{soln} are the solubilized Ni concentration present in the aqueous phase at zero time and time *t*, respectively. Ni_T is the total Ni concentration present in the primary sludge.

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All experiments were conducted in triplicate and mean values with standard deviation of parameters have been expressed as results.

Kinetic Studies

Rate of Ni solubilization through bioleaching can be described by the following empirical equation [8]:

$$\frac{dC_A}{dt} = k_m (C_{A,0} - C_{A,t}) \quad \text{--------------- (2)}$$

Integrating the above first-order equation between limits of initial and final values of Ni concentration and time (at t = 0, C_A = 0 and at t = t d, C_A = $C_{A,t}$) results in the following equation:

$$\ln\left(\frac{C_{A,0}}{C_{A,0} - C_{A,t}}\right) = k_m t \quad \text{---------------- (3)}$$

Where$C_{A,0}$ and $C_{A,t}$ are the total Ni concentration available in the primary sludge and concentration of solubilized Ni in the aqueous phase of leached solution at time t during the process. k_m is the bioleaching rate constant and is obtained from the slope of the plot, $\ln(C_{A,0}/(C_{A,0} - C_{A,t}))$ *vs* time. The analysis of sludge bioleaching mechanism is of immense importance for designing and further application of the process.

Results and Discussion

Characteristics of Sludge

The physico-chemical characteristics of the sludge revealed that the sludge was found to be alkaline in nature. Nitrogen and phosphorus content in the sludge was estimated to be 4,564 and 2818 mg/Kg, respectively. The estimated levels of sodium, potassium and calcium were 303, 214, 20551 mg/Kg, respectively. It was observed from the analysis that the heavy metal, Ni was abundantly present in sludge. The concentration of total Ni present in the sludge was found to be 12850 mg/kg which poses highly toxic and hazardous to the environment when it disposed without treatment.

Variation in pH and ORP during Bioleaching

In the inoculated experiment changes in pH and ORP show significant changes whereas, no changes were observed in control without bacteria. This is due to the conversion of elemental sulfur to metal sulphuric acid by bacterial catalysis. It was observed that at 28, 31, 34, 37, and 40 °C the pH values decreased from 3 to 2.76, 2.53, 2.44, 2.36, 2.02, and 2.23, respectively. Among the experiments, 37 °C showed a tremendous decrease in pH, thereby facilitating bacterial growth. The variation in pH during the bioleaching process is shown in Figure 1.

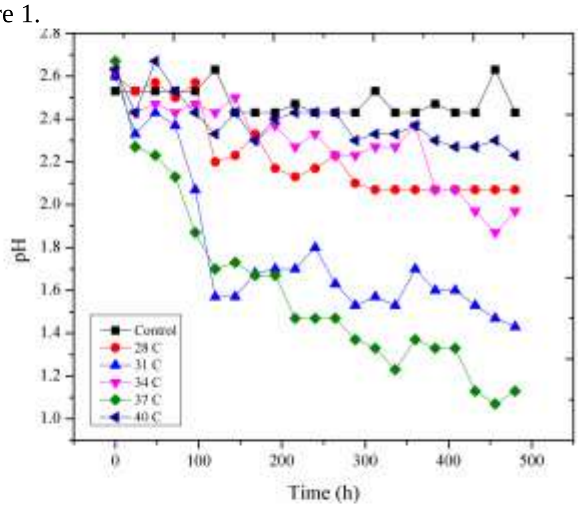

Figure 1. Variation in pH during bioleaching of Ni at different temperatures.

The sludge ORP of the control increased slowly as compared to those with inoculums. The variation in ORP during bioleaching process is shown in Figure 2. In the control experiment, the change in ORP was from 245 to 257 mV. Significant change in ORP of the bioleaching medium was observed in experiments with varying temperatures (from 28 °C to 40 °C). At the end of 20th day, the flask maintained at 37 °C showed considerable increase in ORP (from 268 to 625 mV). It was also observed that ORP increased from 256, 261, 248, and 255 mV to 545, 554, 590, and 595 mV for the respective experiments with 28, 31, 34, and 40°C temperature. The increase in ORP showed a similar trend as decrease in pH with respect to different temperatures. The rate of ORP increase took place in the order of 37 °C > 34 °C > 31 °C > 40 °C > 28 °C, and it is well supported by the pH profiles. The results showed that the culture had rapid growth at the temperature of 37 °C with low pH levels and high ORP. That indicated the presence of good oxidizing environment in leaching media at this temperature.

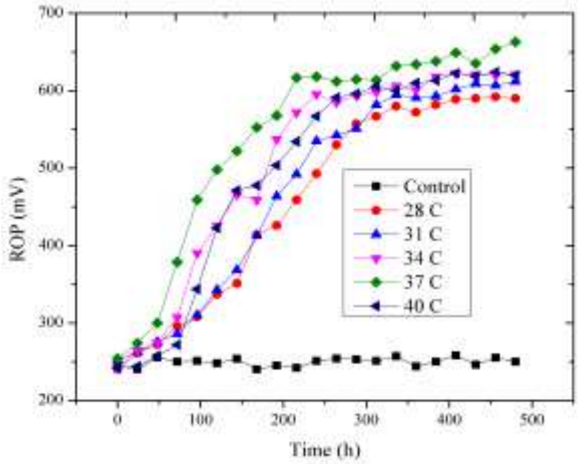

Figure 2. Variation in ROP during bioleaching of Ni at different temperatures.

Effect of Temperature on Ni Removal

Figure 3. shows the bioleaching of Ni from the sludge at different temperatures such as 28, 31, 34, 37, 40 °C. The experimental results revealed that Ni bioleaching is greatly influenced by the temperature. Ni solubilization was reached the maximum in a relatively short period of time at 37 °C. After 30 days of treatment, the bioleaching efficiencies of Ni were 79.16%, 80.14%, 84.57%, 90.5% and 85.62% at the experiments at 28, 31, 34, 37, and 40 °C, respectively. It has been reported that the bioleaching behavior of metals strongly depends on their chemical forms in the original sludge.

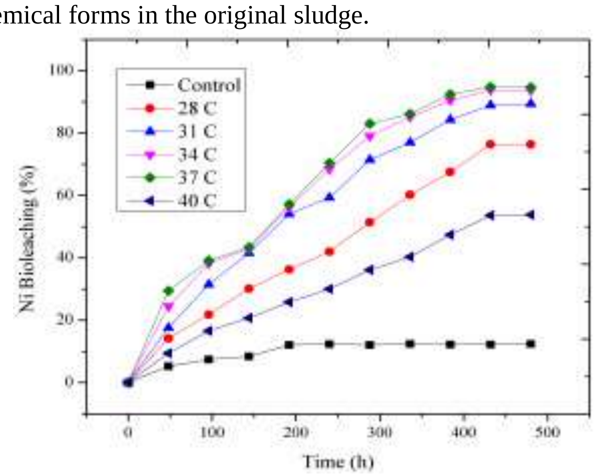

Figure 3. Ni bioleaching percentage at different temperatures.

The experimental data show that the removal efficiencies of heavy metal with respect to temperature took place in the order of 37 °C > 40 °C > 34 °C >31 °C > 28 °C.

Therefore, the better heavy metal solubilization requires treatment preferably an optimum temperature of 37 °C.

Kinetic Studies

The values of rate constant attained at experiments conducted at different temperatures such as 28, 31, 34, 37 and 40 °C were 0.043, 0.048, 0.054, 0.071, 0.060 d^{-1}, respectively for the removal of Ni and the graph is represented in Figure 4. It is evident that the temperature strongly influences the rate of Ni bioleaching and the maximum rate was acquired at 37 °C.

Conclusion

The present study showed that the bioleaching using sulfur-oxidizing bacteria, *A. ferrooxidans* was effective in removing Ni from the electroplating sludge. Ni solubilization efficiencies were observed for experiments carried out at different temperatures. Maximum bioleaching efficiency of Ni was achieved to be 90.5% at 37 °C. The kinetics for bioleaching was studied for reaction rate constant of Ni removal from the sludge. It is very obvious that the values of bioleaching rate constant were high in the treatment at 37 °C. This study clearly demonstrates the practicability and design strategy of detoxification system for electroplating sludge to remove Cr using bioleaching process, which thereby provides a solution to control the toxicity levels in the environment.

Acknowledgement

The authors are grateful to JCT College of Engineering and Technology for providing the infrastructure facilities.

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