Kinetic studies on copper metal leaching from e-waste using organic acid

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Abstract:
Accumulation and disposal of e-waste is a problem that our society faces today. Metal recovery from e-waste is normally achieved by hydrometallurgy, which is a slow and hazardous process that has a negative environmental effect and high operating costs. In this study bioleaching of e-waste was performed in a batch reactor using acetic acid. The most common metals found in e-waste are copper and silver. The kinetics of the reaction between e-waste dissolved in acetic acid was studied and it was determined to be a first-order reaction with a regression coefficient of 0.99.

Keywords: Bioleaching, organic acid, kinetic study, copper

1. Introduction
Bioleaching is thought to be one of the most promising technologies without an excessive amount of capital funding, labor want, and power consumption. [1][2]. In recent years, a vast amount of research has been accomplished on the bioleaching of metals from various samples, including sludge, fly ashes, sediments, soils, batteries, etc.[3–11]. WEEE (waste of electric and electronic equipment) is made up of several metals such as copper, nickel, iron, aluminum, and zinc. E-waste is rich in valuable metals, mostly silver, gold, and platinum (PGMs), which are used in electronics because of their high conductivity and compound robustness. [3]. In 2019, the world produced a record 53.6 million metric tonnes of electronic waste.[12]. Following the current growth rate of e-waste, an ASSOCHAM-EY joint report, titled ‘Electronic Waste Management in India’ estimated India is to generate 5 million tons of e-waste by 2021. Computer equipment and cell phones were also listed as the primary waste generators in India, according to the report. [13].

The toxicity of these metals (especially heavy metals) for human health and the environment, as well as the economic benefits of electrical waste as a secondary source of rare and precious metals, necessitate metal recovery from e-waste [3][14–16]. Bioleaching is a simple bio-hydrometallurgical process with the following benefits: higher performance and safety, lower operating costs and energy usage, easy management of e-waste, operation at atmospheric pressure and room temperature, no need for skilled labour, and little implementation of industrial requirements [11][14][1]. The method of dissolving metals with large quantities of chemical substances (acids) is known as hydrometallurgy. This procedure often generally requires waste pre-treatment. However, it is a slow and risky operation with high operating costs and a negative effect on the environment. [3][17].

Bio-leaching process overcomes these negative impacts as it uses organic acids to separate electronic scrap and precious metals. The kinetic study is a significant step in the understanding of the essence and mechanism of the leaching process. [18]. This research aims to gain insight and comprehend the kinetic parameters so that the order of the reactions in which copper is extracted from e-waste can be calculated.

2. Methodology
The electronic waste was collected from local mechanic stores. The parts were dismantled and then ground into fine pieces using a crushing stone. Figure 1 shows the flake-like particles that were used to experiment. 2 grams of crushed e-waste was immersed in 20 mL concentrated HCl and 5 mL HNO₃ for 20-30 minutes while the digestion process was observed. The presence of copper in the samples was analyzed by using Atomic absorption spectrophotometer. (Analyst. Along with copper(19.8mg per gram of e-waste), the quantity of silver (0.274mg per gram of e-waste) was also prominent. The calibration curve (figure 2) was made with the help of a standard solution having concentrations of 10, 20, 50,100, 200, and 500 ppm. 1500 grams of this sample was immersed in 6 liters of 1M of acetic acid for 8 hours in a continuously stirred batch reactor. The samples were collected at a frequency of 15 minutes each for 8 hours. Figure 2 shows the calibration curve with a correlation curve value of 1. A total of 33 samples were collected for a full run of 8 hours of experimentation.
3. Results and discussions

Leaching kinetics is controlled by either a diffusion mass transfer of the reactant through a liquid boundary layer or ash layer (unreacted Goethite structure) or a chemical reaction on the ore surface. [19]. Figure 3 represents the concentration of copper extracted in different time intervals. It is observed that the concentration of copper increases gradually from zero as the experiment progresses. A heterogeneous reaction mechanism was used to investigate the reaction between copper (solid) and acetic acid (liquid). Linear regression was used to determine the experimental data's fit to the integral rate equations (figure 4). Table 1 summarizes the estimated regression coefficients for kinetics regulated by various rate equations.

| Order of the reaction | Kinetic equation | Regression coefficient |
|----------------------|------------------|------------------------|
| First order reaction | \( t/\tau = -\ln(1-\alpha) \) | 0.99                   |
| Second order reaction| \( t/\tau = \alpha(1-\alpha) \) | 0.911                  |

Table 1. Kinetic equations and their regression coefficients for linearity.

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4. Conclusions

One of the most common metals used in electronic components is copper. Bioleaching of e-waste using acetic acid to extract copper was done. The results show that the reaction that occurs is a first-order reaction. Further scope for the study includes the dissolution kinetics of the particle interactions. In this, we can say that by seeing from the graph this reactor follows the first-order reaction as it very near to 1 i.e. 0.99 where second-order follows near to 1 i.e. 0.91 there is a chance of further study on this topic to deep study on dissolution kinetic to identify the shape of the particle that comes under the maximum.

5. References

[1] Xiang Y, Wu P, Zhu N, Zhang T, Liu W, Wu J and Li P 2010 Bioleaching of copper from waste printed circuit boards by bacterial consortium enriched from acid mine drainage J.
4

Hazard. Mater. 184 812–8

[2] Priya A and Hait S 2018 Extraction of metals from high grade waste printed circuit board by conventional and hybrid bioleaching using Acidithiobacillus ferrooxidans Hydrometallurgy 177 132–9

[3] Bayat B, materials B S-J of H and 2010 undefined Comparative evaluation of microbial and chemical leaching processes for heavy metal removal from dewatered metal plating sludge Elsevier

[4] Cerruti C, Curutchet G, Biotechnology E D-J of and 1998 undefined Bio-dissolution of spent nickel–cadmium batteries using Thiobacillus ferrooxidans Elsevier

[5] Gu X and Wong J W C 2004 Identification of inhibitory substances affecting bioleaching of heavy metals from anaerobically digested sewage sludge Environ. Sci. Technol. 38 2934–9

[6] Lombardi A, Research O G J-W and 2002 undefined Biological leaching of Mn, Al, Zn, Cu and Ti in an anaerobic sewage sludge effectuated by Thiobacillus ferrooxidans and its effect on metal partitioning Elsevier

[7] Mishra D, Kim D, Ralph D, Ahn J, management Y R-W and 2008 undefined Bioleaching of metals from spent lithium ion secondary batteries using Acidithiobacillus ferrooxidans Elsevier

[8] Wu H, technology Y T-E and microbial and 2006 undefined Metal extraction from municipal solid waste (MSW) incinerator fly ash—Chemical leaching and fungal bioleaching Elsevier

[9] Zheng G, Zhou L and Wang S 2009 An acid-tolerant heterotrophic microorganism role in improving tannery sludge bioleaching conducted in successive multibatch reaction systems Environ. Sci. Technol. 43 4151–6

[10] Zhu N, Zhang L, Li C, Management C C-W and 2003 undefined Recycling of spent nickel–cadmium batteries based on bioleaching process Elsevier

[11] Anon Biorecovery of copper from converter slags: Slags characterization and exploratory ferric leaching tests Elsevier

[12] Forti V, Balde C, Kuehr R and Bel G 2020 The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential

[13] Anon Electronic waste: the need to reuse, repair, recycle and safely dispose

[14] Baniasadi M, Bahaloo-Horeh, Mousavi N and Farnaud S M & 2019 Advances in bioleaching as a sustainable method for metal recovery from e-waste: A review the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International http://creativecommons.org/licenses/by-nc-nd/4.0 Elsevier

[15] Natarajan K A 2019 Biotechnology for environmentally benign gold production Horizons in Bioprocess Engineering (Springer International Publishing) pp 263–99

[16] Ilyas S, Ruan C, Bhatti H N, Ghauri M A and Anwar M A 2010 Column bioleaching of metals from electronic scrap Hydrometallurgy 101 135–40

[17] Jagannath A, Shetty V and Saidutta M B 2017 Bioleaching of copper from electronic waste using Acinetobacter sp. Cr B2 in a pulsed plate column operated in batch and sequential batch mode Elsevier 5 1599–607

[18] Sahu S, Kavuri N C and Kundu M 2011 Dissolution kinetics of nickel laterite ore using different secondary metabolic acids Brazilian J. Chem. Eng. 28 251–8

[19] Levenspiel O 1999 Chemical reaction engineering vol 38

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