Recovery of Indium from Mobile Phone Touch Screen Using Adapted *Acidithiobacillus ferrooxidans*

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Abstract: The toxicity of heavy metals has important role in thermophilic microorganism growth in bioleaching of e-waste. The mobile phone touch screen has high concentration of several heavy metals that caused negative effect on bacterial activity and metals recovery. In the present investigation, *Acidithiobacillus ferrooxidans* was adapted to powder of mobile phone touch screen. The serial subculturing approach was used for bacterial adaptation with heavy metals. The experiments began with 0.1 wt/vol.% pulp density eventually increase to 2.5 wt/vol.%. All experiment conducted in 100 ml 9k medium at the initial pH 2 and 2% (v/v) inoculums. The effective parameters such as pH, Eh, Fe^{3+}, cell concentration were studied and the results confirmed as well as each other. Indium recovery for adapted cell, non-adapted cell and control were $100\%_{(adapted)}$, $10\%_{(non\text{-}adapted)}$, $1\%_{(control)}$, respectively. Finally, it is essential that the bacteria become adapted with the heavy metals and consequently an acceptable bioleaching process will be achieved.

Key words: Bioleaching, adaptation, e-waste, *Acidithiobacillus ferrooxidans*.

1. Introduction

In recent years, the amount of solid electro nic waste generation increased and it is a big problem for society, governments and the technology industry, therefore the developing countries will face a great challenge [1]. Among the e-waste the mobile phones waste generation is growing quickly because of the lifetime of these electronic devices is generally 1-3 years [2]. The mobile phone is composed of different parts such as battery, display and electronic boards and according to research approximately 80% of materials in mobile phone is recyclable [3]. Screens are one of the most important parts of mobile phones that contains glass, organic materials and indium which is present in a layer is called indium-tin oxide (ITO). The important point is 70% of indium consumption related to ITO production [4]. Indium is a rare metals and present in small amount (0.24) ppm in the crust of earth and it is obtained as by-product of zinc mining about 1-100ppm [5] The amount of indium in mobile phone screens can be up to 250 ppm. In finally recovery of indium from mobile phone waste is necessary for return to the consumption cycle.

In recent decade, the recovery of metals from e-wastes is performed using biotechnology process. Bioleaching means to employ the microorganisms to solubilize and recover metal from solid waste [6]. There are many advantages for bioleaching process in comparison to conventional methods such as lower cost, minimization of use of chemical materials [7], low energy requirement, decrease the requirement for natural resources and the landfill spaces [6] as well as there is little disadvantages for this method such as longer leaching time and the restrictions for the bacteria [8]. One of these limitations is high toxic of heavy metal concentrations [6]. The mobile phone touch screen has high concentration of heavy metals such as Sr, Ni,Cr. The bacterial activity decreases when the microorganism exposure with mobile phone touch screen due to three reason: 1) decreasing in oxygen and carbon dioxide transmission rate, 2) mechanical injury to the bacterial cells as a result erosion between the cells and particles of waste, 3) the toxic effects of metal ions on bacterial cells [9].The adaptation of *A. ferrooxidans* cells to heavy metal ion performed by serial sub-culturing method and according to this the metal concentration in the medium increased gradually [9]. The adaptation criterion plays crucial role in adaptation process [10] Xia et al (2008) reported that adaptation criterion is based on cell concentration and when cell concentration reached to 10^7 cells/ml can be adapted bacteria [11]. Astudillo and Acevedo showed the adaptation criterion was notable appearance the amount of dissolved copper, iron and a Fe^{+2}/Fe^{+3} ratio under one. in this research adaptation criterion is considered cell concentration and Its value is 5×10^7 cells/ml [12].

Mobile phone contains a variety of valuable materials, such as metals, glass, plastics so process for adaptation of the bacteria will be more complex [3]. In this study main purpose was investigation of various parameters such as pH, Eh, Fe^{3+}, cell concentration during the adaptation and impact of adaptation on the metal recovery.

2. Materials and Methods

2.1. Microorganism and Bacterial Culture

The native strain of *Acidithiobacillus ferrooxidans* (PTCC 1647) was provided from the Iranian Research Organization for Science and Technology (IROST) in Tehran. The 9K medium contained 3 g $(NH_4)_2SO_4$, 0.5 g K_2HPO_4, 0.5 g $MgSO_4$. $7H_2O$, 0.1 g KCl, 0.01 g $Ca(NO_3)_2$ and 44.22 g $FeSO_4$ as an energy source for growth of *A. ferrooxidans* solved in 1 L distilled water.

2.2. Adaptation Technique and Analysis

Adaptation was performed in 250 m erlenmeyer flask with 9K medium in an incubator at 140 rpm and 30 °C. The flasks were inoculated with 2% v/v of active culture and Initial pH was adjusted to 2 with sulfuric acid. The adaptation process was done by serial subculturing method, the concentration of mobile phone screen powder increased from 1 to 25 g/L (pulp density 0.1%-2.5%) in this method when the number of bacteria cell was bigger than 5×10^7 cells/ml the bacteria adapted and can transfer to higher pulp density Inductively coupled plasma optical emission spectrometry (ICP-OES) was used to detect metal concentration in mobile phone screen powder and represented in Table 1.

Table 1. Chemical Composition of the Mobile Phone Touch Screen Using ICP

Element	Concentration(mg/kg)
Al	93561
Sr	20575
In	69
Mn	340

2.3. Analytical Methods

The ferric ion concentration in solution measured by5-Sulfosalicylic acid (SSA) testing method. In this method 0.1 mL of the culture solution was mixed with 3 mL of 10% 5-sulfo-salicylic acid (SSA) followed in 100 mL of distilled water in finally the light absorbance was measured at 500 nm using UV–VIS (Optizen 3220UV, Korea) [13]. Eh meter (model: Metrohm, 691) was used to monitor the Eh change during adaptation process also the acidity of the solution was measured by pH meter (model: CP-500L, IsTek). The bacteria cell number counted by a hemocytometer under a phase-contrast microscope (Zeiss, Germany). The flasks shaked inside the incubators (Wise Cube, South Korea). Metal ion concentration was analyzed by ICP-OES (Vistapro, Australia). The Phenom XL Scanning Electron Microscope (SEM) was applied for investigation of surface morphology of the powder before and after bioleaching.

3. Results and Discussion

3.1. Variation of pH

The change of pH in a variety of pulp density is shown in Fig. 1. Initially, the pH increases because of two reasons, the first reason is acidconsuming by *A. ferrooxidans*. The bacteria for growth consumed oxygen and protons and oxidized ferrous ions Eq. (1):

$$Fe^{2+} + 0.25O_2 + H^+ \xrightarrow{A.ferrooxidans} Fe^{3+} + 0.5H_2O \quad (1)$$

The second reason related to powder structure that is neutral. This claim is based on the pH determination analysis according to this analysis a 1 gr of powder of sample was dissolved in 50 ml of distilled water [14] and placed in a shaker incubator was observed pH of solution was fixed in the range of 7. this analysis proved powder neutrality. Finally the pH increases until the third day and then pH decreases because of the ferric ion hydrolysis and protons released (Eq.2-4) [15].

$$Fe^{3+} + H_2O \leftrightarrow Fe(OH)^{2+} + H^+ \quad (2)$$

$$Fe^{3+} + 2H_2O \leftrightarrow Fe(OH)_2^{\ +} + 2H^+ \quad (3)$$

$$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+ \quad (4)$$

Initial pH for all pulp density was adjusted at 2. As can be seen in Fig. 1 with increasing the pulp density, highest value of pH rise to, 3.5>3.4>3.01>2.86, respectively related to 2.5, 2, 1.5 and 1 wt/vol % of pulp densities Which shows the activity of bacteria reduced.

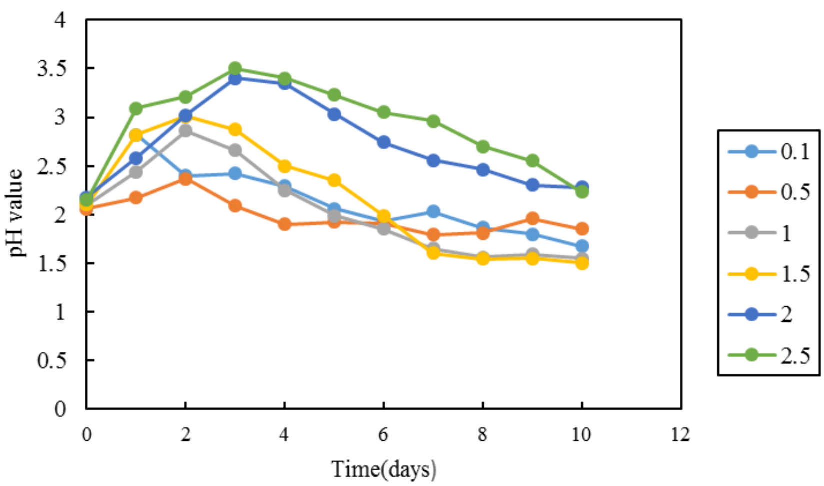

Fig. 1. The changes of pH value over time during adaptation process with variety of pulp densities (% w/v).

3.2. Oxidation-Reduction Potential and Fe^{3+}

In Fig. 2 shows the trend of ORP and Fe^{3+} during adaptation process. A rapid increase in the ORP and Fe^{3+} can be observed at the beginning of the process because of *A. ferrooxidans* used Fe^{2+} as energy source for growth and converted to Fe^{3+} as expressed by Eq. 1. Also, according to the nernst equation (Eq. 5) with increasing the Fe^{3+}/Fe^{2+} ratio the Eh value rises. In the pulp densities 0.1–1.5 wt/vol.% maximum ORP value was in the range of 500 mV and then reached stability which indicates the bacteria is in the stationary phase.

$$E = E^{0} + 0.06 \log\left(\frac{Fe^{3+}}{Fe^{2+}}\right) \tag{5}$$

After the addition of higher pulp density 2and 2.5 wt/vol.%, the highest ORP values decreased and stability at 400mv. Also the trend obtained for Fe^{3+} is shown in Fig. 3. The total Fe^{3+} concentrations are increased for all pulp density due to bacterial activity. The maximum concentration of Fe^{3+} was 7000ppm at lowest pulp density (0.1 wt/vol.%,) with increasing pulp density until 2.5 wt/vol.%, the Fe^{3+} concentration decreased down to 100ppm. In high pulp density the bacterial activity decreased due to decreasing in oxygen and carbon dioxide transmission rate, mechanical injury to the bacterial cells result in erosion between the particles of waste and the cells and the toxic effects of heavy metal ions in bacterial cells.

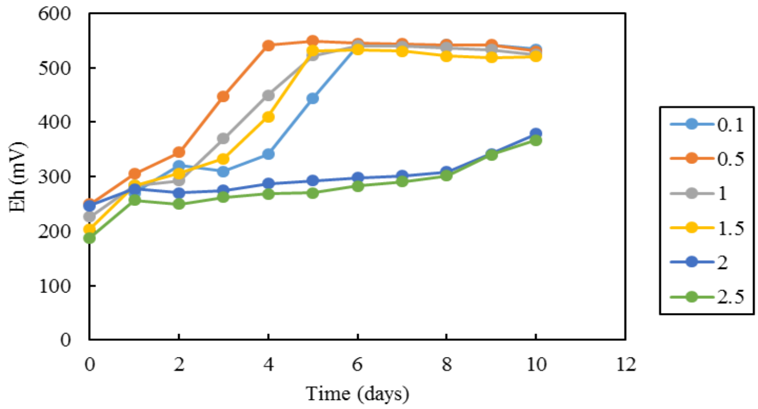

Fig. 2. ORP variation over time during adaptation process with variety of pulp densities (% w/v).

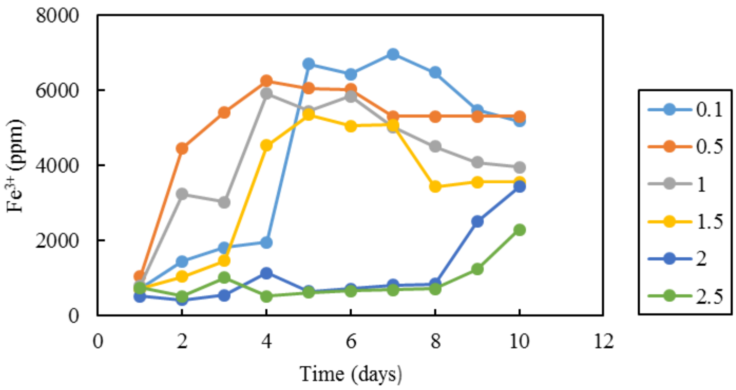

Fig. 3. The changes of concentration of ferric iron (Fe3+) production by A. ferrooxidans over time during adaptation process with variety of pulp densities (% w/v).

3.3. Cell Concentration

The growth of *A. ferrooxidans* is characterized in Fig. 4. The different phases (i) the lag phase, (ii) the growth phase, (iii) stationary phase and death phase can be seen for pulp densities in range 0.1–1.5 wt/vol. %. The effect of pulp density on length of lag phase can be observed when bacteria exposed to 0.1 wt/vol% pulp density shock came to bacteria so the lag phase is 8 days, in the pulp density 0.5 wt/vol.% lag phase was reduced to 3 days then by increasing pulp density to 1.5 wt/vol lag phase increased. finally maximum time for lag phase in the pulp density 2, 2.5 wt/vol.% is 10 days.

As can be seen in Fig. 4 the maximum cell concentration of bacteria was reduced from 10^8 cells/mL for 0.5 wt/vol.% to 1.3×10^7 cells/mL for 2.5 wt/vol.% in the period of 10 days, because of metal ions created complex with protein molecules in bacteria and will be decreased its performance through inactivation of enzymes [16].

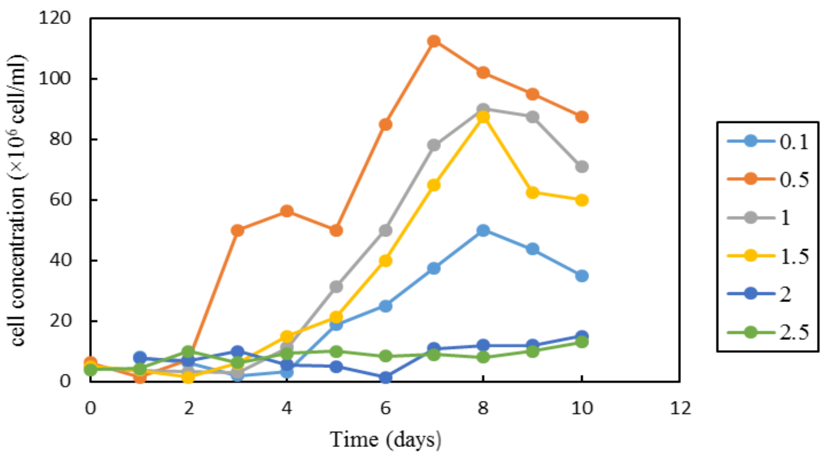

Fig. 4. The changes of bacterial cell concentration of *A. ferrooxidans* over time during adaptation process with variety of pulp densities (% w/v).

3.4. SEM

In Fig. 5 shows surface morphology of the mobile phone touch screen sample by scanning electron microscope (SEM) before and after bioleaching. In Fig. 5(a) shows a clear surface of powder without coarseness before bioleaching process, the effect of bioleaching and bacterial activity on powder particle represents in Fig. 5(b).the image indicated clog formation and a significant scattering on powder particle.

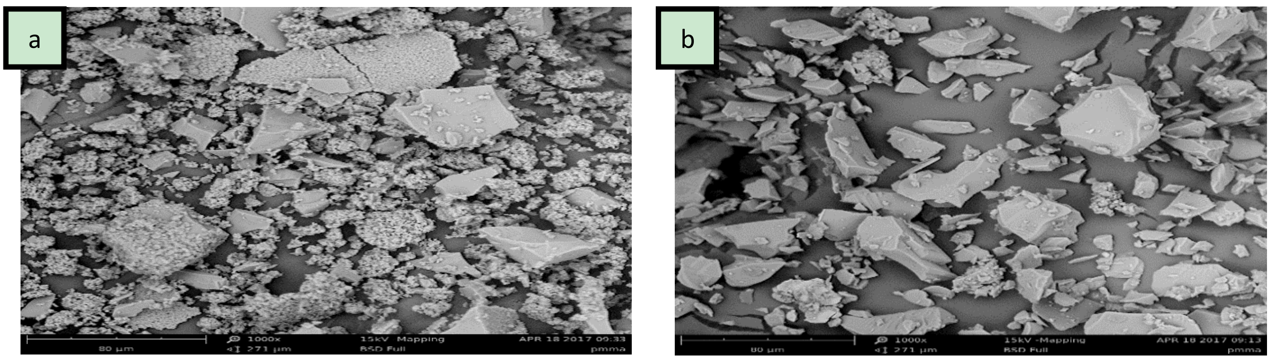

Fig. 5. SEM image of particle of mobile phone touch screen (a) before bioleaching and (b) residues bio-leached by *Acidithiobacillus ferrooxidans* in 9K medium after 10 days; T = 30 °C, rpm = 140, pulp density = 1.5 wt/vol.%.

3.5. Recovery

In Fig. 6. the total Indium efficiency is shown for (a)adapted pure culture of *A.ferrooxidans* (b) non-adapted pure culture of *A.ferrooxidans* (c) control which performed in the presence of medium and 15g/l of sample without bacterial inoculation. The maximum indium recovery was observed with the adapted culture at 100%. These indium removal efficiencies were obtained during 10 day of bioleaching process. Therefore, by comparing the results obtained for the indium recovery between the adapted culture and the non-adapted culture it can be concluded adaptation is needed to reach higher indium recovery and the bioleaching process has been completed successfully. The nan-adapted(b) bacteria could not resist the toxicity of powder therefore its growth stopped and the Indium recovery decrease down to 10%.

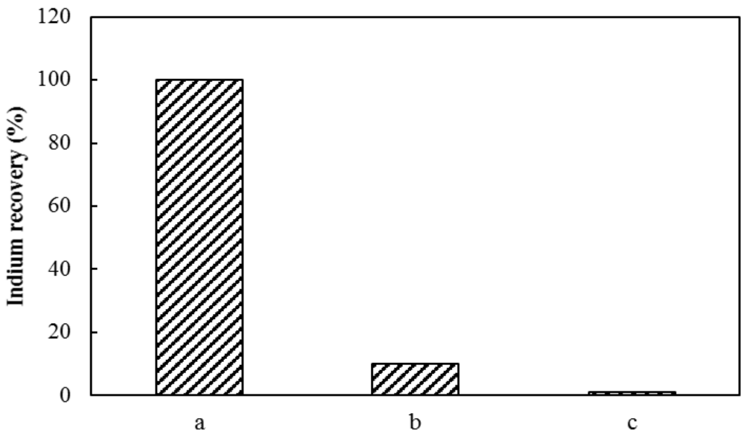

Fig. 6. Indium recovery after 10 days (a) adapted pure culture of *A.ferrooxidans* (b) non-adapted pure culture of *A.ferrooxidans* (c) control of *A.ferrooxidans*.

4. Conclusion

Adaptation of bacteria in the presence of mobile phone touch screen powder was successful. There are some reasons that can justify this phenomenon. The first reason is that there is a logical relationship between the trends of effective parameters such as pH, Eh, Fe^{3+} and cell concentration. The second reason refers to the performance of adapted and non-adapted bacteria which indicates that indium recovery percentage of adapted bacteria is 100% while no significant recovery was achieved by non-adapted bacteria. The whole adaptation process was done when having a wide range of pulp density from 0.1- 2.5 wt/vol.%. When bacteria encounter a considerable amount of heavy metals, they will die because of the toxicity created in the media. Therefore, in order to solve this problem, it is essential that the bacteria become adapted with the heavy metals and consequently an acceptable bioleaching process will be achieved.

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