Multi-objective optimization of bioleaching from e-waste in a bubble column bioreactor by *Penicillium simplicissimum* utilizing molasses as the carbon source

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Abstract

Mobile phones are known as the most widely used electronic instruments, and an enormous number of discarded mobile phones are generated. The present work used a pure culture of *Penicillium simplicissimum* in a bubble column bioreactor to extract Cu and Ni from mobile phone PCBs (MPPCBs) waste. Molasses was used as an efficient carbon source to enhance bioleaching efficiency and increase the cost benefits. The adaptation phase was done at Erlenmeyer flasks to reach 40 g/l of pulp density. The most significant parameters, including pulp density, aeration, molasses concentration, and their interaction, were optimized to leach maximum possible Cu and Ni using central composite design in response surface methodology. 96.94% of Cu was recovered under 8.8% (v/v) of molasses, aeration rate of 0.29 (l/min), and pulp density of 10 g/l. The optimized condition of Ni leaching was 1.9% (v/v) of molasses, aeration rate of 0.37 (l/min), and pulp density of 10 g/l leading to 71.51% recovery.

Keywords: Fungi; Metal recovery; Mobile phone PCBs; Molasses, Response surface methodology; Scale-up
Introduction

Electronic waste (e-waste) covers all electrical and electronic instruments that have been discarded without reusing [1]. E-waste is the fastest-growing part of the world’s domestic waste stream in the past two decades [2] and is estimated to reach about 52.2 million metric tons by 2021 [3]. To overcome the social, environmental, and economic perspectives, appropriate e-waste management is required; recycling of e-waste is the target [4]. Bioleaching is a safe, novel, and economic process that mobilizes metals by oxidizing metals or making complexes [5].

Most of the presented works in the literature have studied the improvement of the bioleaching of waste PCBs in shake flasks using a low amount of sample powder leading to reproducibility and representativeness problems [6]. The bubble column bioreactor is suggested as an attractive reactor for bioleaching processes due to the rapid mixing, high mass and heat transfer, well gas dispersion, and low shear stress on microorganisms [7]. Although there are too many researches on metal biorecovery from waste PCBs, no such study on column bioleaching application for metal leaching from e-waste using *P. simplicissimum* is reported yet. Previous research has studied the bioleaching of base metals from waste PCBs in the mediums containing molasses, sucrose, sugar, and whey as the energy sources using *Penicillium simplicissimum* in Erlenmeyer scale. It was concluded non-conventional medium and using the named cheap carbon sources increase the metal recovery rather than using the expensive sucrose. Also, sugar and molasses were introduced as efficient carbon sources for Cu and Ni recovery. 90% of Cu and 89% of Ni were extracted in non-conventional mediums [8]. For this study, a bubble column bioreactor was utilized to recover nickel and copper from MPPCBs using *P. simplicissimum*. Molasses was used as the energy source to enhance bioleaching efficiency and increase the cost benefits.
Experimental

MPPCBs wastes were purchased from the e-waste trading companies in Tehran, Iran. They were reduced to an average diameter of 2cm using a hammer mill. The particle size was reduced to 75-149 μm diameters. The concentration of Cu, Ni, Au, Ag, and Fe were identified respectively 28 ppm, 2.5 ppm, 3415 ppm, 801 ppm, and 77 ppm by inductively coupled plasma optical emission spectrometry (ICP-OES, 730-ES, Varian, America).

The heterotrophic fungus of *P. simplicissimum* (PTCC 5129) in lyophilized form was obtained from Persian Type Culture Collection, Tehran, Iran. Many solubilized metals from MPPCBs are toxic. On average, each step lasted a week. The adaptation phase, in a step of 1 g/l, and finally, a maximum adaptable limit at 40 g/l, was done in 100 ml medium utilizing 250 ml Erlenmeyer flasks and a shaking incubator (5082u, Labcon, South Africa) at 30 ℃ and 130 rpm.

Further tests were done in a glass bubble column bioreactor. After seven days of fermentation, the medium was filtered, and the amounts of released metals were measured using atomic absorption spectroscopy (AAS) (Carl Zeiss Technology, AAS5EA, Germany).

Response Surface Methodology (RSM) shows the effect of various significant parameters. In this study, the weight of waste powder (pulp density) (in the range of 10-40 g/l), the concentration of Molasses (1-10 v/v%), and the aeration intensity (between 100-400 ml/min) in the bioreactor were selected as the independent variables (n=3). 16 runs, with two center points, were designed to explain the bioleaching efficiency of Cu and Ni in the batch bubble column bioreactor, using *P. simplicissimum* adapted to 40 g/l powder of MPPCBs.

Results and discussions

According to Software analysis the leaching efficiencies of Cu were obtained in the range of (12.9-60.5%). The highest leaching efficiency was related to the condition of the pulp density of 16.1
g/l, aeration rate of 340 ml/min, and the molasses concentration of 8.2% (v/v). The lowest amount of Cu was recovered under the 25 g/l of the e-waste powder, aeration rate of 400 ml/min, and the molasses concentration of 5.5% (v/v). The Ni recoveries were in the range of (19.9-70.5%) for the 16 experiments. The highest Ni recovery gained was related to the 25 g/l of the e-waste powder, aeration rate of 250 ml/min, and the molasses concentration of 5.5% (v/v). The condition with the lowest recovery of Ni was attributed to the pulp density of 33.9 g/l, aeration rate of 340 ml/min, and the molasses concentration of 8.2% (v/v).

Figure 1 represent the contour plot of Cu for various pulp density of MPPCBs powder. Part (a), (b), and (c) are plotted at 10, 25, and 40 g/l of MPPCBs powder, respectively and Figure 2 indicates the contour plots of Ni leaching efficiency for various concentrations of molasses. Part (a) and (b) are plotted at 3% (v/v) and 10% (v/v) of molasses, respectively.

The software suggested the optimum conditions to maximize metal recovery after doing the designed experiments. So, two separate experiments were designed to gain maximal leaching efficiency under the suggested optimal conditions with the desirability of 100 96.94% of Cu was recovered under 8.8% (v/v) of molasses, aeration rate of 0.29 (l/min), and 10 g/l of the e-waste powder. The optimized condition of Ni leaching was 1.9% (v/v) of molasses, aeration rate of 0.37 (l/min), and pulp density of 10 g/l leading to 71.51% recovery.
Conclusion

The Ni and Cu leaching efficiencies in the bubble column bioreactor from mobile phone PBCs were optimized using *Penicillium simplicissimum* by CCD-RSM Design Expert 10.0.7. The effects of molasses concentration, pulp density, the aeration rate, and their interaction on the process were identified by ANOVA. 96.94% of Cu was recovered under 8.8% (v/v) of molasses, aeration rate of 0.29 (l/min), and 10 g/l of the e-waste powder. The optimized condition of Ni leaching was 1.9% (v/v) of molasses, aeration rate of 0.37 (l/min), and 10 g/l of the e-waste powder leading to 71.51% recovery.

References:


