

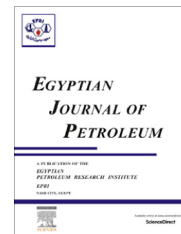
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FULL LENGTH ARTICLE

Practical study on the electrochemical simultaneous removal of copper and zinc from simulated binary-metallic industrial wastewater using a packed-bed cathode

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Received 4 December 2014; revised 17 March 2015; accepted 29 March 2015

KEYWORDS

Simultaneous removal of Cu and Zn;
 Packed-bed cathode;
 Electrolytic flow reactor;
 Current efficiency

Abstract In this work, electrochemical-simultaneous removal of copper and zinc from simulated binary-metallic industrial wastewater containing different ratios of copper to zinc was studied using a packed-bed continuous-recirculation flow electrolytic reactor. The total nominal initial concentration of both metals, circulating rate of flow and nominal initial pH were held constant. Parameters affecting the removal percent and current efficiency of removal, such as applied current and time of electrolysis were investigated. Results revealed that increased current intensity accelerated the removal of metals and diminish current efficiency. It was also observed that selective removal of both metals is possible when the applied current was of small intensity. Moreover, the factors that led to loss of faradaic efficiency were discussed.

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1. Introduction

The toxicity of heavy metals has been known for many years. Most heavy metals belong to persistent toxic substance [1]. They are long-lasting substances that can build up in the food

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Peer review under responsibility of Egyptian Petroleum Research Institute.

<http://dx.doi.org/10.1016/j.ejpe.2015.03.017>

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chain to levels that are harmful to human and ecosystem health [2]. This fact has provoked an international response to the problem. Therefore, the protection of the environment has become a major issue and crucial factor for the future development of industrial processes, which will have to meet the requirements of sustainable development [3].

Industrial effluents from electroplating industries contain high amounts of heavy metal ions, such as Cd, Cr, Cu, Ni and Zn. Of metals used in electroplating, only 30–40% is

effectively utilized; the rest contaminates the rinse waters. Rinse waters may contain up to 1000 mg/L of the polluting heavy metals [4].

Both copper and zinc, at reasonable doses, are essential for human health, animal metabolism and the activity of many microorganisms. The excessive ingestion of copper, however, brings about serious toxicological concerns, such as vomiting, cramps, convulsions, or even death [5]. Also, excessive zinc could cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anemia [6].

Electrochemistry offers promising approaches for the prevention of pollution problems in the process industry. The inherent advantage is its environmental compatibility, due to the fact that the main reagent, the electron, is a 'clean reagent' [3].

Researchers with various cell designs have attempted the electrochemical removal of copper from real or simulated solutions with varying degrees of achievements and improvements [7–14]. Few researches, however, were carried out on the electrolytic removal of zinc from solutions containing the element. Abbas et al. [15] used an electrolytic cell with a porous cathode of amalgamated copper screen to remove zinc from synthetic aqueous streams. They reported that an exponential decay of zinc concentration with respect to time was observed and the removal was about 90% after 300 minutes when the initial concentration was 150 mg/L and flow rate 3.2 L/h. Bertazzoli et al. [16] used a three dimensional, reticulated vitreous carbon cathode, under mass transport controlling condition, for the removal of Cu, Pb and Zn from simulated solutions that contained a single metal of the three at a time; i.e. they did not study the metal removal when the three cations co-exist in one solution. For the separation of heavy metals from solutions containing two or more metal cations, fewer researches were carried out. The process becomes more complicated as there is a possibility of simultaneous discharge of several cations. Doulikas et al. [17] studied the selective electrodeposition of Cu, Pb, Cd and Zn from a solution containing these ions. They reported that the four metals could be selectively separated under potentiostatic conditions; copper ions were reduced first whereas zinc ions were reduced last accompanied with hydrogen evolution. Manuela et al. [18] proposed a hybrid process which combines electrodeposition, for Cu recovery, followed by a sequential alkaline precipitation for recovery of nickel and zinc from contaminated biomass used in the bioremediation of electroplating effluents. Basha et al. [19] attempted the removal of Cd, Cu, Ni, Pb, Zn and Fe by electrochemical reduction with the help of electrolytic 3-dimensional cell using graphite particle packed cathode and noble oxide coated Ti anode. Their presented data indicate that the removal of all metals reached 60–80% after 60 minutes by using current density of 2 and 3 A dm⁻² and flow rate of 61 mL min⁻¹. This may imply that Zn, less noble than Cu, was reduced at the same time with Cu which is more noble. Walsh [20] studied the selective removal of Cu(II), Cd(II), and Zn(II) from a mixed metal solution using reticulated vitreous carbon, flow-by, cathode operated in a batch recycle mode. He reported that by controlling the applied potential Cu could be firstly removed followed by Cd and Zn was removed last.

In this work, experiments were carried out to remove Cu and Zn present in a simulated binary-metallic waste solution using electrochemical batch recirculation cell under

galvanostatic mode of operation. The effects of Cu to Zn weight ratio and intensity of the applied current on the removal percent of both metals, generation of hydrogen, as a byproduct, and current efficiency of removal were investigated.

2. Experimental

Fig. 1 is a schematic representation of the experimental setup. The cylindrical column was made from acrylic, to enable better visualization of the process. The inside diameter and the height were 10 cm and 70 cm, respectively. A height of 70 cm was enough to give a sufficient disengagement height to allow any entrained carbon particles to separate from the treated solution leaving the column in order to keep the mass of the bed unchanged. The column is separated by a flow distributor into upper and lower parts. The distributor, perforated acrylic plate, had holes of 1 mm diameter arranged in equilateral triangular configuration of 5 mm pitch. The upper surface of the distributor was covered with a porous polyethylene membrane to enhance better flow distribution.

The counter electrode was 5 cm diameter disc installed in the lower part of the column while the working electrode (carbon bed) was in the upper part. The current feeder to the packed bed was cup-shaped opened from lower side and the upper side was a perforated disc that had holes of 1 cm diameter arranged in equilateral triangular configuration of 1.5 cm pitch; this was to facilitate the upward flow of the treated solution and to permit the escape of generated gases on the bed surface. The cup was supplied with 6 additional legs, of 5 cm length and 1 cm width, to give good contact with the particulate bed. Both current feeder and counter electrode were made of 316 Stainless Steel. The vertical distance between the two electrodes was 5 cm.

The packed bed material was prepared by crushing carbon pieces of very high purity, (XRD analysis revealed the presence of the single peak of carbon), and collecting the sieved fractions of 1–4 mm diameter particles; the average particle size

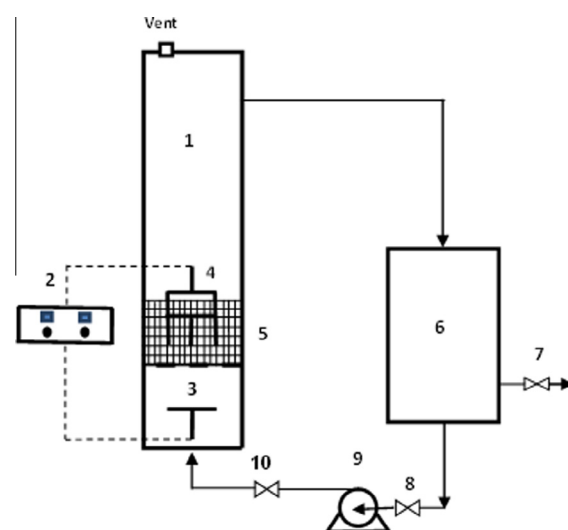


Figure 1 Schematic representation of the experimental setup. (1) Column; (2) power supply; (3) counter electrode; (4) current feeder; (5) carbon bed; (6) reservoir; (7) sampling valve; (8) flow regulating valve; (9) centrifugal pump; (10) flow regulating valve.

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