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Heavy metals recovery from industrial wastewater using Taguchi method

N.M.S. Kaminari [a,*], D.R. Schultz [a], M.J.J.S. Ponte [b], H.A. Ponte [c], C.E.B. Marino [c], A.C. Neto [d]

[a] *Federal University of Paraná, Laboratory of Environmental Technology (LTA), PO Box 19011, 81531-990 Curitiba, PR, Brazil*
[b] *Federal University of Paraná, Department of Mechanical Engineering, PO Box 19011, 81531-990 Curitiba, PR, Brazil*
[c] *Federal University of Paraná, Department of Chemical Engineering, PO Box 19011, 81531-990 Curitiba, PR, Brazil*
[d] *Federal University of Paraná, Department of Statistics, PO Box 19011, 81531-990 Curitiba, PR, Brazil*

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Abstract

The aim of this work is to study an electrochemical reactor using metallic particles as cathode for lead, copper and nickel ions recovery from acidified aqueous solutions for different process parameters as metallic ion concentration, current density and bed expansion. The reactor performance was evaluated considering the system efficiency and energy consumption. Taguchi method was selected as the statistical technique since it allows the main effects to be estimated with a minimum number of experimental runs. Moreover, it makes use of fractional factorial and orthogonal arrays to identify the factors, which present the greatest influence on the system, and the optimum factor setting for each experiment run. The highest current efficiency obtained were 75.8%, 89.9% and 30.3% for lead, copper and nickel, respectively.

Keywords: Heavy metals recovery; Electrochemical reactor; Taguchi method

1. Introduction

Metals contamination in waste water is a serious problem for several industrial sectors such as metal finishing and the electronics industry. The outlet wastewater from these industrial processes normally contains metal concentration higher than the acceptable limits settled by law [1]. Metal removal or recovery from aqueous waste streams is becoming an increasingly important issue because of growing economic and environmental concerns. Electrodeposition is an interesting method to recover metals such as copper, lead, zinc, silver, among other metals. This method has a high efficiency for the copper case because of its high reduction potential [2].

Nowadays, this wastewater is discharged within the permitted concentrations limits of suspended solids and dissolved salts. Demanding excessive chemicals, this process results in large volumes of waste for disposal with no recovering process fesability.

Electrodeposition is a clean technology, offering an efficient way of controlling pollution as it provides removal of transition and heavy metals by redox reactions without the disadvantages of conventional treatment. The inherent advantage is its environmental compatibility, due to the fact that the main reagent, the electron, is a "clean reagent", [3,4]. The literature on electrolytic metal ion removal from aqueous solutions using porous electrode cells is extensive [5–10]. By flowing simulated effluents containing metal ions through three-dimensional porous cathodes, it is possible to achieve both high mass transfer rates and large surface areas for the electrochemical reaction.

Fluidized-bed electrolytic cell was developed by Backhurst and co-workers [11] and applied originally to electrochemical synthesis and fuel cell [12]. It consists of a steel particles bed, which is fluidized by an upward flow of electrolyte. The whole bed is made cathodic by a "feeder" electrode inserted into the bed with an inert anode immersed in the electrolyte. The fluidized-bed cathode differs from the conventional planar electrode in two main aspects. Firstly, as the cathode is a bed of particles, it has a larger relation surface-area per volume. Thus, for any given cell current, the current density at the cathode surface is very low [13,14]. Secondly, a very high degree of agitation exists within the bed, which reduces the Nernst diffusion layer, increasing the limiting diffusion currents. Both these effects reduce the concentration polarization and, under favorable conditions, make it possible to electrowin metals down to parts-per-million concentrations without significant loss of current efficiency.

* Corresponding author.
E-mail address: nicemsk@hotmail.com (N.M.S. Kaminari).

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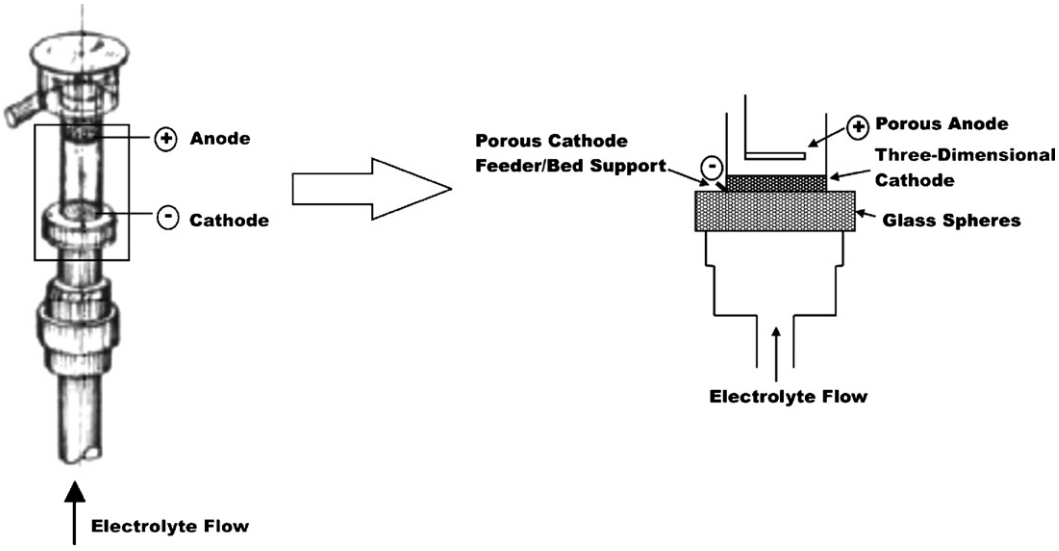

Fig. 1. Electrochemical reactor (flow-through cell) and detailed view of the reactor.

Therefore, fluidized-bed electrochemical reactors (FBE) are attractive for their capacity and operability in many fields of electrochemical technology, especially in the treatment of dilute or complex solutions [15]. Several applications have been considered, e.g., fuel cells, hydrogen peroxide synthesis, ore flotation and organic electrosynthesis, but the best applications are expected especially in extraction metallurgy [16,17].

Two main arrangements in respect to the direction of the electric current and electrolyte flows are possible. They are denoted as flow-through and flow-by arrangements. In this work it was used the flow-through electrodes configuration, which has been commonly adopted for work on a small scale.

To evaluate the current efficiency and the energy consumption the Taguchi method was selected as a statistical technique once it allows the main effects to be estimated with a minimum number of experiment runs. A design plan is based on the use of orthogonal arrays introduced by Taguchi. Through the application of Taguchi's S/N ratio, the optimal operational condition from an experiment can be determined. It leads to several implications: (1) reduced experimental time, (2) identification of a fractional design containing the best operational condition that can be studied for full experimentation, (3) within a subset of a fractional design plan, the best operational condition can be found, and (4) significantly reduces of experimental cost since a minimal number of simulation runs is required to identify the best operational condition [18].

2. Experimental

2.1. Materials

The experimental apparatus consisted of an electrochemical reactor, a centrifugal pump to recirculate the solution, a manometer and a reservoir. The experiments were been conducted at ambient temperature and under galvanostatic conditions. The current control was achieved by using a constant current source (Power Supply—model EMG 18134).

The electrochemical reactor, illustrated in Fig. 1, was made from a cylinder of acrylic with an internal diameter of 4.44 cm and 20 cm length. The bed was composed by carbon steel particles with 1 mm diameter and 20 mm bed height. In order to obtain a uniform fluid distribution inside the bed, it was used a distributor composed by a packed glass spheres ($d = 1$ mm) and 15 mm height bed. The electrical contact with the fluidised-bed was obtained through a steel feeder electrode (cathode). The anode was a stainless steel disc, located at 2 cm from the top of the particles bed.

The current efficiency was determined by spectrophotometer analysis of lead, copper and nickel concentration at samples of electrolyte withdrawn from the system at the beginning and ending runs. The spectrophotometer used was the UV-vis—model FEMTO 600 Plus. The time spent for run was about 180 min.

Table 1
Composition of the solutions

Solutions	Initial concentration	H_3BO_3 concentration (M)	$NaNO_3$ concentration (M)	H_2SO_4 concentration (M)	$E_{standard}$ *vs.* NHE (mV)
1	500 ppm [Pb (2+)]	0.5	0.044	–	−126
2	750 ppm [Pb (2+)]	0.5	0.040	–	
3	500 ppm [Cu (2+)]	–	–	0.4	340
4	750 ppm [Cu (2+)]	–	–	0.4	
5	500 ppm [Ni (2+)]	–	–	0.02	−230
6	750 ppm [Ni (2+)]	–	–	0.02	