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Galvanostatic Removal of Lead from Simulated Chloride Wastewaters using a Flow-by Fixed Bed Electrochemical Cell: Taguchi approach

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Abstract— The Taguchi parameter design approach was used to find the optimal conditions for electrolytic Pb(II) removal using a flow-by fixed bed electrochemical cell composed of a vertical stack of stainless steel screens. The investigated process parameters were initial metal ion concentration, current, flow rate, and mesh number of screen. Removal, current efficiencies, and energy consumption were considered as responses for the optimization of metal removal. An orthogonal array L_9, the signal-to-noise(S/N) ratio, and the analysis of variance were used to analyze the effect of selected process parameters and their levels on the performance of Pb(II) removal.The results indicated that concentration and current have the major effect on performance of lead removal. Flow rate and screen mesh number have lower contribution on the performance of Pb(II) removal and their contributions are close in all responses. The optimum values of control factors were Pb(II) initial concentration 200ppm, current 0.58A, flow rate 7l/min ,and mesh number 40 wire/in. The highest current and removal efficiencies were 48.5% and 89.7% respectively with energy consumption (2.43kwhkg^{-1}). The results of confirmatory runs under the optimum conditions indicated that this methodology is more efficient in optimizing the process parameters.

Index Terms— Heavy metals, Electrochemical reactor, Lead, Flow-by electrode, Taguchi method.

1 INTRODUCTION

THe increase in legal pressures and restrictions are forcing industries to accept responsibility for the treatment of wastewaters in an attempt to minimize pollution. Wastewater generated during the processing of lead-acid batteries contains Pb (II), which is very toxic to the environment and to living beings. Thus, before discharging this wastewater into sewers, effluent treatment must be carried out in order to decrease the concentration of the metallic ion [1].A number of techniques have been used to remove lead or other heavy metals from wastewater effluents; including chemical precipitation [2], electrodialysis [3],ion exchange process[4,5], adsorption onto activated carbon [6, 7],low cost adsorbents such as kaolin, bentonite, blast furnace slag and fly ash [8],ion imprinted polymer [9,10], organic-based ligand precipitation [11],membrane and reverse osmosis processes [12]. The industrial utilization of these methods has been found to be limited, because of the high capital and operating costs and/or the ineffectiveness in meeting stringent effluent standards [13].

Electrochemical treatment methods are attractive since they can combine metal removal with metal recovery in its pure form, without sludge generation. The inherent advantage of this technology is its environmental compatibility due to the fact that the main reagent, the electron, is a 'clean reagent' [14, 15]. The increasing use of electrochemical technologies in the environmental treatment is due to the utilization of porous materials as three dimensional electrodes in the design of electrochemical cells [16]. One of the main advantages of this kind of electrode derives from the fact that it can provide high specific surface area as well as high mass transfer rate.Two principal configurations for the three dimensional electrodes have been developed: the flow-through configuration, where fluid flow and current are parallel; and the flow-by configuration, where the fluid flows perpendicularly to the current [17].Unfortunately the flow- through porous electrode has met with a limited success on the commercial scale in view of the non-uniformity of current and potential distribution, poor selectivity and low conversion per pass [18]. To avoid these shortcomings, attention has been directed to the flow-by electrode which has other advantages such as the possibility of using it in the form of a divided or undivided filter press type cell [18-23]. Several types of flow-by electrode have been proposed, for example, carbon or metal particles [24, 25], metallic or metal plated foams and felts [26, 27], and reticulated vitreous carbon [28]. The main drawback of these electrodes, however, is the fact that continuous metal deposition leads to clogging of the pores by the deposited metal. In addition, they suffer from the high pressure drop .Besides, flow-by fixed bed electrodes made of small particles, metal felt and metal foam may entrap gas bubbles(H_2) which are likely to evolve simultaneously with the main reactions from dilute solutions with a consequent increase in the cell resistance and electrical energy consumption [29].The use of screens and expanded metals in building three dimensional electrodes offers many advantages, such as high specific area, high turbulence-promoting ability, high porosity and relatively low pressure drop, ease of coating with a catalyst, and ready availability at modest cost [30]. In addition, they present a rigid structure and are relatively easy to construct.

Specifically for Pb (II) ions, several works on their removal from aqueous solutions using three dimensional electrode were reported [31-38] .In all these studies, experiments were carried out by changing one of the variables and fixing the others. However, the variables may interact strongly. These interactions can be determined using Taguchi design of experiment, which also allows determination of the optimal

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