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Optimization of packed bed electrolysis of zinc anode casing of spent dry cell batteries

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ABSTRACT

In this research work, statistical analysis and optimization of the production of electrolytic zinc powder from zinc anode casing of spent dry cell batteries by packed bed electrolysis technique were carried out using response surface methodology (RSM). The analysis considered the effect of electrolyte temperature (30–50 °C), stirring rate (250–350 rpm), and current density (500–1000 A/m^2) on the cathodic current efficiency, anodic current efficiency, specific energy demand, and powder productivity. The experimental design was based on Box-Behnken design using quadratic polynomial equations for predicting the mathematical models. The results indicate that the proposed models predict the responses adequately within the limits of the packed bed electrolysis process parameters being used. The current density, the second order effect of both current density and stirring rate, and the two level interactions of temperature and current density are the most significant model terms associated with cathodic current efficiency. It was also found that, RSM can be considered as a powerful tool in the optimization of packed bed electrolysis.

1. Introduction

A very large quantity of zinc-carbon type dry cell batteries is used in our daily life. They are non-rechargeable (primary cells) so once they are discharged they become useless and are discarded (Belardi et al., 2011; Rayovac Corp, 2014). Most of the spent batteries are dumped in landfills instead of being recycled and constitute a source of heavy metals in the percolate collected at the bottom of the landfill (Karnchanawong and Limpiteeprakan, 2009; Xara et al., 2009). The costs to maintain landfills are increasing and it is becoming more and more difficult to obtain, from local authorities, the authorization for opening up new landfills (Belardi et al., 2011).

The pyrometallurgical and hydrometallurgical approaches have been applied for recovery of zinc from the spent dry cell batteries (Belardi et al., 2011; Salgado et al., 2003; Xiao et al., 2009; Buzatu et al., 2013; Rácz and Ilea, 2013; Buzatu et al., 2014). The pyrometallurgical process or the use of critical treatment conditions for Zn recovery has been found to have a bad effect on the environment due to emissions, secondary waste streams, and hazardous work environments (Baba et al., 2009). Therefore, the development of intensified hydrometallurgical, zero-waste treatment routes is highly recommended (Toro et al., 2012).

The packed bed electrolysis process is another efficient method used to recover metal powders from spent raw materials without application of both leaching and electrowinning techniques (Owais et al., 2015a; Owais, 2015; Owais and Friedrich, 2003; Owais and Gepreel, 2013). By applying this method, high-quality electrolytic metal powders can be produced through the direct electrolytic refining of the exhausted materials. This process depends on utilizing the anode particles, which are placed in a basket made from titanium, to collect the particles and to conduct electricity to them. One of the main advantages of this technique is the continuous feeding of the anode particles into the basket; moreover, there is no need to add an external source of metal ions to the electrolytic cell as is usually done with the electrowinning technique. The produced zinc powder can be employed in both chemical and metallurgical industries. Moreover, it can be used for the production of amalgam alloy, which is used in dental fillings. Zinc powder can also be used for different applications in electronic industries. In addition, it is used in alkaline batteries, rocket fuel, and cosmetics (Sharifi et al., 2009).

Generally, the characteristics of the packed bed electrolysis process are directly influenced by many process input parameters including current density, composition and the properties of the electrolyte, electrolysis temperature, stirring rate, presence of additives and/or impurities in the electrolyte, and nature of the electrodes and electrodeposit (Gupta, 2003). Therefore, the packed bed electrolysis process can be considered as a multi-input/multi-output process. Unfortunately, a common problem that has faced the manufacturer is the control of the process input parameters to obtain an economical product.

Traditionally a time-consuming trial and error development effort should be used to determine the input parameters for every electrolytic

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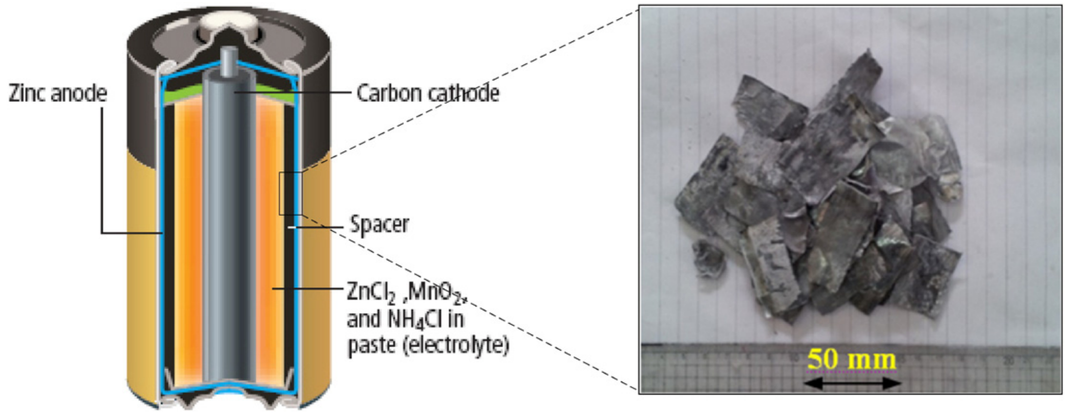

Fig. 1. Casing of secondary batteries as zinc anode sheets.

process to obtain a final product with the desired specifications. At that point the process product is examined to figure out if it meets the specifications or not. The electrolytic process parameters can be finally decided to produce an electrolytic product that nearly meets the necessities.

Recently, design of experiment (DoE) considers the common used methods to create numerical relationships between diffirent input parameters that affect the electrolytic process variables in order to focus the parameters that prompt the sought electrolytic product. The statistical design of experiments is an efficient procedure for planning experiments so that the data obtained can be analyzed to yield valid and objective conclusions. The two main applications of experimental design are screening, in which the factors that influence the experiment are identified, and optimization, in which the optimal settings or conditions of an experiment can be found.

Classic optimization procedure can be carried out by varying any of the process conditions and fixing the other conditions. When multiple process variables are involved, it becomes more difficult to investigate the overall system using the classical procedure. The recent statistical designs consider all the process parameters simultaneously and hence provide the possibility for evaluation of all the effects at once. The response surface methodology (RSM) can be considered one of the most widely optimization techniques used to describe the performance of the industrial processes (Somasundaram et al., 2014; JurateVirkutyte et al., 2010; Li et al., 2010; Li et al., 2011). RSM has been successfully applied in several studies for process analysis, optimization, and the variables formulation (Reisgen et al., 2012).

To the best of the authors' knowledge, there is no information available in the open literature on the characterization and optimization of direct packed bed electrolysis of zinc spent secondary batteries to produce electrolytic zinc powder by statistical approach. Hence, this research work aims to develop mathematical models using RSM to predict, describe, and evaluate the cathodic current efficiency, anodic current efficiency, specific energy demand, and powder productivity of the direct packed bed electrolysis of zinc anode casing of spent secondary batteries. The optimization of direct packed bed electrolysis process will be also considered.

2. Experimental procedure

Zinc anode casing sheet was separated from the internal paste material in the spent battery, cut into smaller sizes, and washed using distilled water. The zinc sheets had a dimension of 1 mm in thickness, 20–30 mm in length, and 10–20 mm in width (Fig. 1). The sheets were put into a graphite anode basket (100 mm width, 100 mm active height, and 50 mm thickness). A 230 g/L sodium hydroxide solution

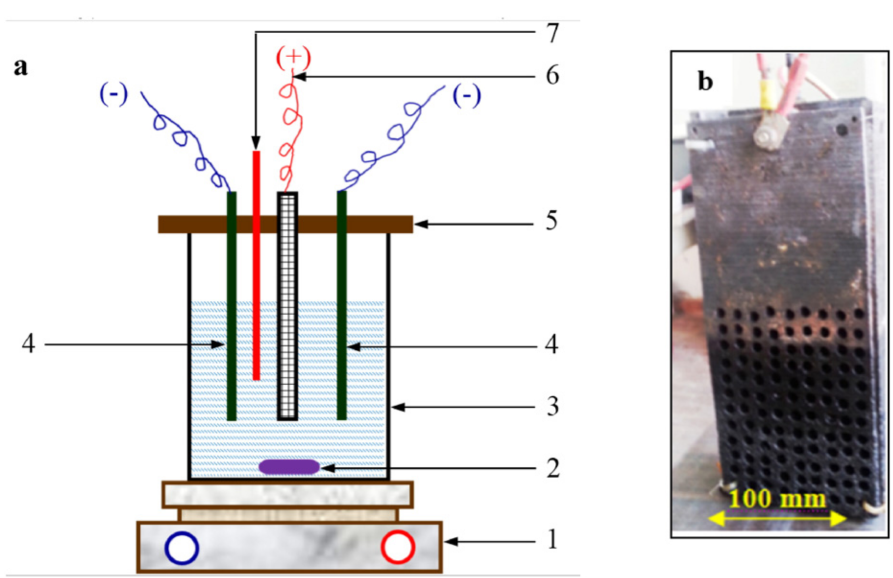

Fig. 2. a)Sketch of bench scale experimental setup [*1-hot plate, 2-rotating magnet, 3-a 5 l backer glass filled with 3 Lelectrolyte, 4-two stainless steel cathode sheets, 5-cell cover, 6- graphite anode basket filled with zinc casing, and 7-thermometer*], and b) graphite anode basket filled with zinc casing.