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ORIGINAL ARTICLE

Electrochemical treatment of simulated sugar industrial effluent: Optimization and modeling using a response surface methodology

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Abstract The removal of organic compounds from a simulated sugar industrial effluent was investigated through the electrochemical oxidation technique. Effect of various experimental parameters such as current density, concentration of electrolyte and flow rate in a batch electrochemical reactor was studied on the percentage of COD removal and power consumption. The electrochemical reactor performance was analyzed based on with and without recirculation of the effluent having constant inter-electrodes distance. It was found out that the percentage removal of COD increased with the increase of electrolyte concentration and current density. The maximum percentage removal of COD was achieved at 80.74% at a current density of 5 A/dm^2 and 5 g/L of electrolyte concentration in the batch electrochemical reactor. The recirculation electrochemical reactor system parameters like current density, concentration of COD and flow rate were optimized using response surface methodology, while COD removal percents were maximized and power consumption minimized. It has been observed from the present analysis that the predicted values are in good agreement with the experimental data with a correlation coefficient of 0.9888.

1. Introduction

The industrialization and modification of manufacturing processes have resulted in an increase in the volume of wastewater discharge into the environment which causes water pollution (Manisankar et al., 2003). India is one of the largest producers and consumers of 22 million tons of sugar per annum in the world. The sugar industries utilized huge quantities of water in the results to produce large amounts of wastewater. In the industry, around 1500–2000 L of water is used and generates about 1000 L of wastewater per ton of cane crushing. The effluent mainly comes from floor washing and condensate water, leakage and spillages of sugarcane juice from valves and glands of the pipeline, syrup and molasses in a different section, solid

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waste etc. The environmental issues are disposal of effluent containing molasses, wastewater, solid waste and by-products into the ecosystem and land after treatment of wastewater in the sugar manufacturing process.

The wastewater produced in the sugar manufacturing process has a high content of organic material and subsequently high Biochemical Oxygen Demand (BOD), particularly because of the presence of sugars and organic material in the beet or cane. In cane processing, the typical levels of BOD are 1700–6600 ppm in the untreated effluent , the Chemical Oxygen Demand (COD) is from 2300 to 8000 ppm and the total suspended solids are up to 5000 mg/L, and the ammonium content is high (WORLD BANK GROUP, 1998). The wastewater may also contain pathogens from contaminated materials or production processes. The effluent often generates odor and dust, which need to be controlled. Many processes have been developed to treat this effluent such as electrochemical oxidation (Guven et al., 2009; Mancera et al., 2010), biosorption (Martín-Lara et al., 2010), membranes separation (Hinkova et al., 2002), and biochemical oxidation (Prasad et al., 2006). Only a limited number of researches have been carried out using electrochemical oxidation for the treatment of the sugar industrial effluent.

Electrochemical treatment method may be considered as an economically alternate process under such conditions when conventional treatment fails to reduce pollution (Guven et al., 2008). The electrochemical oxidation is one of the advanced oxidation processes, potentially a powerful method of pollution control, offering high removal efficiencies in compact reactors with simple equipments for control and operation. These processes generally operate at a low temperature and usually prefer adding electrolyte solutes to increase the conductivity of wastewater. In recent years, there has been a growing interest in the treatment of industrial effluents by electrochemical methods. Many researchers had investigated the electrochemical oxidation for the treatment of various types of wastewater containing phenol (Maa et al., 2009), pentachlorophenol (Upendra et al., 2008), tannery (Rao et al., 2001), olive mill (Canizares et al., 2006), coffee curing (Bejankiwar et al., 2003), and textile wastewater (Radha et al., 2009), resin (Prabhakaran et al., 2009), pharmaceutical effluent (Abhijit et al., 2005), deproteinated whey wastewater (Guven et al., 2008), distillery spent wash (Krishna Prasad and Srivastava, 2009), dairy manure (Ihara et al., 2006), and organic pollutants (Martinez-Huitle and Ferro, 2006). However, there is no study carried out for the treatment of synthetic sugar effluents by electrochemical oxidation methods.

In addition the electrochemical parameters of the study were optimized statistically by adopting Response Surface Methodology (RSM). RSM is a designed regression analysis to predict the value of a dependent variable based on the controlled values of the independent variables. It leads to the need for an experimental design, which can generate a lot of samples for consumer evaluation in a short period of time, and thus laboratory level tests are more efficient. From the parameter estimates, it can be determined which variable contributes the most to the prediction model, thereby allowing the product researcher to focus on the variables that are most important to the product acceptance. RSM was used to optimize the experimental parameter for a different process, which includes an advanced oxidation process (Otto, 1999), electrochemical oxidation (Gursesa et al., 2002) and adsorption (Montgomery, 2002). The two most common designs used in RSM are the Central Composite Design (CCD) and the Box–Behnken Design (BBD). In the present study, BBD with RSM was adopted to optimize the experimental parameters like various operation parameters such as current density, flow rate and effluent concentration on the COD removal efficiency and power consumption.

The main objective of the present study is to assess the electrochemical oxidation treatment of synthetic sugar effluents using RuO_2 coated titanium as an anode and stainless steel as a cathode. Experiments were conducted in a batch electrochemical reactor with and without recirculation to investigate the effect of operating parameters such as current density, flow rate and concentration of effluent, and effluent on the percentage removal of COD and energy consumption. An attempt has been made to employ BBD using RSM for optimizing the key influencing parameters (i.e. current density, flow rate and effluent concentration) on removal of COD and power consumption in a batch recirculation system.

2. Materials and methods

2.1. Chemical reagents

All the chemicals used in the study were of analytical reagent grade. NaCl (Merck) in high purity was used as a supporting electrolyte. RuO_2 coated on titanium electrodes were obtained from Titanium Tantalum Components Industries, India. Stainless Steel (SS304) electrodes were manufactured in Carbone Lorraine India Pvt. Ltd., India. The simulated sugar effluent prepared by dissolving an appropriate amount of saccharose (1 M) and 0.5 M ammonium carbonate, potassium dihydrogen phosphate and calcium hydroxide in distilled water was used for experimental studies. The wastewater was buffered with sodium bicarbonate to prevent a drop in pH.

2.2. Experimental method

Experimental setup of the batch electrochemical reactor was made up of a cylindrical glass container, closed with a lid which helps fit the electrodes in a position to maintain the inter-electrode distance. An RuO_2 coated titanium expanded mesh served as an anode and stainless steel as a cathode having electrode dimensions of 10×8 cm. The electrodes were connected with regulated power supply (L1606, Aplab Limited) to supply electrical energy to the system. The lid was designed to facilitate the sample collection and the stirring was done with the magnitude stirrer. The synthetic sugar effluent was taken in the electrochemical reactor with a volume of 1000 ml. The experiment was conducted under galvanostatic conditions fixing the reservoir volume in the batch electrochemical reactor. During the electrochemical reaction, the organic compound in the effluent was oxidized at the anode and a reduction reaction occurred at the cathode.

The effect of experimental parameters like current density was varied from 1 to 5 A/dm^2, mediator concentrations from 1 to 9 g/L was studied. During the process, cell voltage was noted down periodically. The samples were collected at various intervals of time for the analysis of organic concentration. The concentration of organics was measured in terms of COD. The COD value was determined by dichromate closed reflux method (APHA, 1995; Balaji et al., 2007).

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