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Response surface modelling and optimization of treatment of meat industry wastewater using electrochemical treatment method

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ABSTRACT

In this present study, electrochemical (EC) treatment was used to treat meat industry wastewater. Effects of EC process variables such as pH, electrolysis time, current density and electrolyte dose on the removal efficiency of chemical oxygen demand (COD) and colour were examined. Four factors three level Box–Behnken response surface design (BBD) coupled with response surface methodology (RSM) was employed to optimize the EC process variables. Second order polynomial models were developed for the responses and three dimentional (3D) response surface plots were used to study the interactive effects of the process variables on the EC treatment efficiency. The experimental results showed that, EC effectively reduced the COD (92%) and colour (98%) of the meat industry wastewater under the optimum conditions such as pH of 7, electrolysis time of 45 min, current density of 35 mA/cm^2 and electrolyte dose of 1.4 g/L, respectively. The operating cost of the treatment process under the optimum conditions is found to be 1.6 \$/m^3.

1. Introduction

Food industry is an important industrial sector that represents 8% of all industries and it is an important consumer of water. Among various kinds of food industries, meat processing industries use approximately 62 Mm^3/y of fresh water from river and canals. The operations of the meat industry can be divided into two major categories: production and processing. Meat production includes all the functions involved in raising flocks of live birds: breeding, hatching, grow-out and feed manufacture [1]. Processing is defined as the functions involved in converting a live bird into meat products and by-products: slaughtering, further processing, rendering, and processing waste handling. Only a small amount of fresh water quantity is a component of the final product in meat industries; the remaining part is wastewater of high biological and chemical oxygen demand, high fat content and high concentrations of dry residues. Since the wastewater contains substantial amounts of proteins, it gives off nasty smells when it is discharged to ecological system [2]. These wastewaters may also contain disease microorganisms and egg parts. Moreover, the contaminant loading of the wastewater discharged from meat processing plants varies seasonally, daily or even on a shift basis. Regardless of a direct or indirect dischargeof this meat industry wastewater, the majority of the soluble and particulate organic material must be removed prior to discharge [3,4]. Depending on the degree of treatment required meat processors have the option of utilizing physical, chemical and biological treatment systems. Each system type possesses unique treatment advantages and operational difficulties. Therefore, there is a critical need to develop a technically and economically viable technique to treat meat industry wastewater [5,6].

Last few years, conventional wastewater treatment methods such as ion exchange, reverse osmosis, co-precipitation, coagulation, complexation, ozonation, biological treatment and adsorption are used for the treatment of various industrial wastewaters. Physical methods like ion exchange and reverse osmosis have proven to be either too expensive or inefficient to remove toxic maters from wastewater [7,8]. At present, chemical coagulation treatments are not used due to disadvantages like high costs of maintenance, problems of sludge handling and its disposal, and neutralization of the treated effluent. The removal of organic matters from industrial wastewaters by adsorption using different materials has also been explored. The major disadvantages of this studied adsorbent are low removal efficiency and higher operating cost. Recent research has demonstrated that an electrochemical treatment method (EC) offers an attractive alternative to above-mentioned traditional methods for treating wastewater [9]. This

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has advantages over conventional treatment methods such as easy automation, maximum removal efficiency, shorter treatment time, low sludge production with reasonable operating cost. In this treatment process anodic dissolution of metal electrode takes place with the evolution of hydrogen gas at the cathode. Electrochemically generated metallic ions from the anode can undergo hydrolysis to produce a series of activated intermediates that are able to destabilize the finely dispersed particles present in the wastewater to be treated. Therefore, this treatment method were used for the treatment of wastewater containing, heavy metals, foodstuff, oil wastes, textile dyes, fluorine, polymeric wastes, organic matter from landfill leachate, suspended particles, chemical and mechanical polishing wastes, aqueous suspensions of ultrafine particles, nitrate, phenolic waste, arsenic and refractory organic pollutants [10]. Meanwhile, process parameters of the electrochemical treatment methods such as pH, electrolysis time, current density and electrolyte dose (NaCl; Sodium Chloride) greatly influence the removal efficiency and its optimization will pay a way to reduce the operating cost with maximum treatment efficiency of EC process.

As is well known, conventional and classical methods of optimization by maintaining other factors involved at an unspecified constant level does not represent the interactive effect of all the factors (process parameters) involved [11]. This method is also time consuming and requires a number of experiments and man power to determine optimum levels, which are unreliable. In recent years, multivariate statistical techniques have been preferred to identify the optimal combination of factors and interactions among factors, which are not possible to identify using the classical method [12]. In addition, these techniques are very useful tools to reduce the treatment time and cost of studies. The experimental design involves estimation of the coefficients in a mathematical model, predicting the response, and checking the adequacy of the model [13]. The most commonly used designs to determine response surfaces are Box–Behnken design (BBD). However, to our best knowledge, no research reports are available on the treatment of meat industry wastewater by electrochemical treatment method using response surface methodology (RSM). Hence, the present study has been made to investigate and optimize the individual and the interactive effect of process variables such as pH, electrolysis time, current density and electrolyte dose on the maximum removal efficiency of chemical oxygen demand (COD) and colour from meat industry wastewater using Box–Behnken response surface design (BBD) coupled with Derringer's desired function methodology. The obtained results will be helpful to the implementation of EC treatment process in industrial level with lower environmental impact.

2. Materials and methods

2.1. Materials

Meat industry wastewater was collected from the local industry near Erode, TamilNadu. The characteristics of meat industry wastewater are determined using APHA standard methods and they are shown in Table 1. All the chemicals used in this study were analytical grade and were purchased from Sigma chemicals, Mumbai.

Table 1
Characteristics of meat industry wastewater.

Characteristics	A	B
pH	7.8	6.8
COD (mg/L)	6785	542
Colour (CU_s(Pt-Co))	568	12

A: Raw wastewater; B: EC treated wastewater; $N = 3$ with standard deviation of ±0.53%.

2.2. Experimental setup

The experimental set up used in this study is shown in Fig. 1, which mainly consisted of a beaker of 1200 mL as a reactor to hold a sample of 1000 mL. Iron (Fe) plates of 4 mm thickness and 50 mm × 50 mm dimensions were used as electrodes. The total effective surface area of electrodes was 50 cm^2; and 0.5 cm gap was maintained at the bottom of the electrodes for easy stirring. The desired current density was maintained constant by means of a precision digital direct current power supply (0–30 V, 0–2 A). All experiments were conducted in batch mode of operation and pH of the wastewater was adjusted using 0.1 N HCl or NaOH. In each experimental run, a wastewater sample was rigorously stirred by a magnetic stirrer. The electrodes were washed with HCl solution (15%W/V) before each run. Following each run, the electrodes were washed with distilled water, dried and used again. After passing each current for each time period (*i.e.*, after each batch experiment), the sample was transferred allowed to settle down. After a settling time of 20 min, the supernatant sample was collected to perform the analysis of COD and colour. All the experiments were performed in three replicates to check the reproducibility.

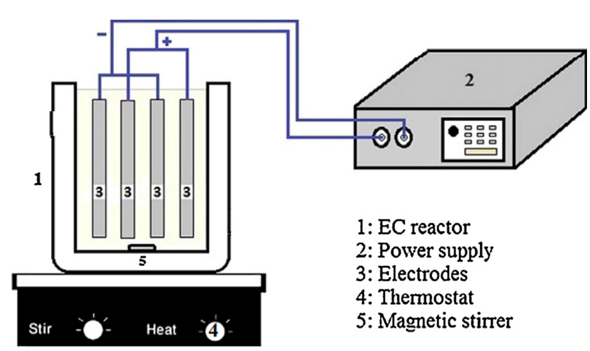

Fig. 1. Schematic diagram of electrochemical reactor.

2.3. Analytical methods

American public health association (APHA) standard methods were used to determine the wastewater characteristics such as initial pH, colour and COD. The removal efficiency (R) was calculated using the following equation [14]:

$$R = \frac{Y_0 - Y}{Y_0} \times 100 \quad (1)$$

where R is removal efficiency (%), Y_0 and Y were initial and final values of COD and colour, respectively.

2.4. Experimental design

In this present study, four factors three level Box–Behnken response surface experimental design (BBD) was used to optimize and investigate the influence of process variables such as pH, electrolysis time, current density and electrolyte dose on the treatment of meat industry wastewater using electrochemical method (EC). Process variables and their ranges were determined based on the single factor experimental analysis which are shown in Table 2. After selection of process (independent) variables and their ranges, experiments were established based on a BBD which consists of 29 experiments with five centre points. The total