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Slaughterhouse wastewater treatment using an advanced oxidation process: Optimization study☆

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ABSTRACT

In this paper, a poultry slaughterhouse wastewater (PSW) was treated in terms of chemical oxygen demand (COD) and color reduction using electro-Fenton (EF) technique under response surface methodology (RSM). The effects of five significant independent variables such as reaction time, pH, H_2O_2/Fe^{2+} molar ratio, current density, volume ratio of H_2O_2/PSW (ml/l) were investigated on the COD and color removal. Experimental data were optimized by Box-Behnken design (BBD) and RSM. The optimum conditions were experimentally found at pH of 4.38, reaction time of 55.60 min, H_2O_2/Fe^{2+} molar ratio of 3.73, current density of 74.07 mA/cm^2, volume ratio of H_2O_2/PSW of 1.63 ml/l for 92.37%COD removal and at pH of 3.39, reaction time of 49.22 min, H_2O_2/Fe^{2+} molar ratio of 3.62, current density of 67.90 mA/cm^2, volume ratio of H_2O_2/PSW of 1.44 ml/l for 88.06% color removal.

1. Introduction

The consumption of poultry meat has increased during the last few decades (Rajakumar et al., 2012). It is led a huge content of waste (Kalyuzhnyi et al., 1998). Poultry slaughterhouses generate wastewater from the various processes such as preprocessing, slaughtering, bleeding, scalding, evisceration, storing and packaging, poultry by-products and rendering (Salminen and Rintala, 2002). The wastewater is characterized by high loads of biodegradable organic compounds such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD), oil and grease, nitrogen and phosphorus due to the presence of suspended solids and colloidal compounds such as blood, protein, fat and cellulose (Salminen and Rintala, 2002; Nery et al., 2001; Debik and Coskun, 2009). The composition of wastewater from the poultry slaughtering industry varies from one plant to another one (Yordanov, 2010). Therefore, these wastewaters should be treated to a standard level according to the environmental protocols (Debik and Coskun, 2009; Bayar et al., 2014). There are several methods for the poultry slaughterhouse wastewater (PSW) treatment which most of them were concentrated on the biological processes such as activate sludge, stabilization ponds, aerobic and anaerobic reactors. However these systems are effective and economic but, they mostly need long hydraulic retention time, large area, high demand of energy (for aeration) and large amount of generated sludge (Bayar et al., 2014; Daneshvar et al., 2007; Nery et al., 2007).

Recently the electrochemical advanced oxidation processes (EAOPs) have been encouraged for the treatment of organic pollutants in aqueous media (Davarnejad and Sahraei, 2015). The most popular EAOP is the electro-Fenton process (Thirugnanasambandham et al., 2013). Electro-Fenton method has several advantages such as large amount of pollutant removal, small amount of sludge production, short reaction time, easy operation, low energy consumption and compatible with environment (Paramo-Vargas et al., 2015; Lee and Shoda, 2008; KirilMert et al., 2010).

In the Fenton reaction, hydrogen peroxide reacts with Fe^{2+} to generate hydroxyl radicals and ferric ions. Fe^{2+} ions are continually regenerated from Fe^{3+} reduction on the cathode surface. Furthermore, hydroxyl radicals and dissolved oxygen simultaneously form from water oxidation on the anode surface. In fact, hydrogen peroxide is added from out of reaction medium and Fe^{2+} ions are provided from the anode electrode (Zhang et al., 2006). Therefore, the hydroxyl radicals degrade the harmful compounds in this process (Gençten and Özcan, 2015; Loaiza-Ambuludi et al., 2013).

In this research, a real poultry slaughterhouse wastewater was treated using the electro-Fenton process. The effective parameters on this process were experimentally and statistically considered and optimized.

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2. Materials and methods

2.1. Wastewater source and characteristics

The wastewater used in this work was collected from Dorsa Chicken slaughterhouse (Arak, Iran). The sample was taken from the equalization basin and stored at 4 °C before conducting experiments and further analysis. The chemical analysis of PSW was shown in Table 1.

2.2. Experimental setup

A glass beaker with 500 cm^3 capacity as reactor was used in all experiments. Electrodes made of iron plates in rectangular shape with dimensions of 2 cm × 0.5 cm. The effective surface area of each electrode was 1 cm^2 and the spacing between them was 3 cm.

In each run, 250 cm^3 of wastewater was poured in the reactor and desired amounts of iron salt ($FeSO_4 \cdot 7H_2O$, Merck grade) and hydrogen peroxide (with purity of 30% purchased from the Merck supplier) were added. Then, the electrodes were connected to the direct current (DC) power supply (fabricated by Kala Gostaran-e-Farda supplier, 30 V and 3 A). The initial waste pH can be changed by sulfuric acid (0.1 N) or sodium hydroxide (0.1 N). During the experiments, pH of the wastewater was measured by a pH-meter (METTLER-TOLEDO, 320). All experiments were performed at atmospheric pressure, constant temperature (25 °C) and stirring speed (400 rpm). At the end of each run, the solution was allowed to settle around 30 min for suspended solids and sludge sedimentation. The sample was then filtered by the cellulose membrane filter with the pore diameter of 8 μm (whatman, 40). The filtered wastewater quality was measured by a UV-Vis spectrophotometer (HACH, US) calibrated by the supplier. The filtered samples were placed in the spectrophotometer with suitable wavelengths in terms of COD (at 228 nm) and color (at 346 nm) while the blank was distilled water (Davarnejad and Nikseresht, 2016). The wavelengths were evaluated by the standard method. For example, COD was determined by acidic digestion (open reflux) method at 150 °C for 2 h, using potassium dichromate as oxidant, followed by titration with iron (II) sulfate and ammonia. In this measurement, pH was adjusted to 4 (Davarnejad and Hosseinitabar, 2016). For calibration chart preparation, an initial sample was diluted in five different volumes (50, 100, 200, 500 and 1000 cm^3) and absorption amounts were taken for these five samples at 228 nm. The similar procedure was carried out for color (at 346 nm), as well. Finally, the electrodes were washed with distilled water to remove any solid residues on their surfaces before each run.

2.3. Experiments design

The parameters optimization by conventional methods needs time, materials, and a large number of experiments. The conventional optimization technique is based on changing one variable when the others were fixed (Mohajeri et al., 2010a). Therefore, experiments statistical design is one of the most useful techniques for each parameter effect consideration on the process with minimizing number of experiments (Kasiri et al., 2008). The response surface methodology (RSM) is a tool for the optimizing and statistical analysis of experimental data (Ghafoori et al., 2014). The RSM also identifies the relationship between the controllable input parameters and the response variable (Cruz-González et al., 2012). In fact, the RSM is used for optimization due to the possibility of several parameters consideration, simultaneously (Suárez-Escobar et al., 2015).

The Design-Expert statistical software (version: 7.0.0) was employed for minimizing number of experiments, optimizing, graphical and regression analysis. It can also estimate the coefficients of the response functions based on a model. The BBD in RSM is an important design tool used for the process optimization. BBD provides comprehensive conclusions and detailed information for smaller number of experiments and interactive effects of operating parameters on all responses (Kabuk et al., 2014).

In this research, a five-factor with three-level BBD in conjunction with RSM was applied to maximize COD and color removal in a poultry slaughterhouse influent. The affecting parameters on the EF reaction were the reaction time (X_1), pH (X_2), H_2O_2/Fe^{2+} molar ratio (X_3), current density (X_4), volume ratio of H_2O_2/PSW (X_5) as independent variables. The COD and color removals were chosen as responses (dependent variables). Thus each factor was coded at three levels (from −1 to +1) and the coding was done by the following equation:

$$x_i = \frac{X_i - X_0}{\Delta X} \tag{1}$$

where x_i is the dimensionless value of an independent variable, X_i represents the real value of the independent variable, X_0 is the real value of the independent variable at the center point, and ΔX is the step change (De Lima et al., 2010). Table 2 shows the independent variables and their levels. Results of the process are reported as function of removal calculated by:

$$Removal(\%) = \frac{C_i - C_o}{C_i} \times 100 \tag{2}$$

where C_i and C_o are initial and final COD (and color) concentrations. Table 3 shows the experimental design matrix obtained by the software.

3. Results and discussion

3.1. Regression model based on ANOVA

Equation (3) which is a second-order quadratic polynomial model (El-Ghenymy et al., 2012) was used to predict the system responses and estimate the coefficients by correlating interaction between the process variables and responses.

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{i<j} \beta_{ij} x_i x_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \varepsilon \tag{3}$$

where Y is the response variables (COD and color removal

Table 1
Characteristics of the used wastewater.

Parameter	Unit	Value
Chemical oxygen demand (COD)	mg/l	2932
Total dissolved solid (TDS)	mg/l	1872
pH	–	6.27
Color	Color unit	100

Table 2
Independent variables and their levels obtained from the BBD.

Symbol	Factor	Coded levels of variables		
		−1	0	1
X_1	Reaction time	10	35	60
X_2	pH	2	5	8
X_3	Molar ratio H_2O_2/Fe^{2+}	0.5	2.75	5
X_4	Current density	20	50	80
X_5	H_2O_2/PSW	0.3	1.22	2.14