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Modeling of by-product recovery and performance evaluation of Electro-Fenton treatment technique to treat poultry wastewater

K. Thirugnanasambandham, S. Kandasamy, V. Sivakumar *, R. Kiran kumar, R. Mohanavelu

Department of Food Technology, Kongu Engineering College, Perundurai, Erode 638052, TN, India

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ABSTRACT

The aim of this study was to investigate and optimize the operating parameters in Electro-Fenton (EF) treatment process such as initial pH, current density, H_2O_2 dose and treatment time on the removal of turbidity and chemical oxygen demand (COD) from poultry processing industry wastewater. Response surface methodology (RSM) coupled with Box-Behnken response surface design (BBD) was employed and significant quadratic polynomial models were developed with high coefficient determination values (R^2). Operating cost of EF process was also determined in optimum conditions. Optimum operating conditions were determined using numerical optimization method and found to be; initial pH of 3, current density of 10 mA cm^{-2}, H_2O_2 dose of 20 ml/l and electrolysis time of 30 min. Under these conditions, 93% of turbidity and 97% of COD were reduced with 0.009 kW h/l of electrical energy consumption (EEC). The sludge recoverd indicated that presence of higher amount of protein.

1. Introduction

Food industry is one of the largest industry sector in India, which is the main source of water pollution [1]. Among various kinds of food industries, poultry processing industry is one of the highly polluting industries, which require great concern with the environmental aspect. The primary steps in poultry processing includes bleeding, scalding or skin removal, evisceration, washing, chilling, cooling, packaging and cleaning [2]. Waste streams from poultry processing can be generalised in to carcasses, skeleton waste, fats, animal faeces, eviscerated organs, blood and waste water [2]. They are rich in protein, nitrogen and minerals like phosphorus. They are used to produce animal feed, cosmetics, fertilizers fish and pet feed. With the drastic development in the poultry processing industrial sector, there is increase in fresh water usage [3,4]. Water is an inevitable and essential raw material for poultry processing industries, thus it discharges harmful wastewater to the ecological system. The large quantity of aqueous waste generated by poultry processing industries has becomes a significant environmental problem when it's discharge into ecosystem without pretreatment [5,6].

In conventional system of poultry wastewater treatment follows coagulation, flocculation, aeration, flotation and biological treatment. Most of the poultry industries, discharged conventionally treated wastewater is into near by water bodies or open lands. Sometimes it is used for irrigation of garden and lawns which leads to outspread of diseases [7]. Drawbacks associated with this conventional wastewater treatment system are high sludge production, which is difficult to process further. If resins or membranes are used for wastewater treatment it has to be recharged or changed periodically. And also this conventional system is less efficient remove some of the biological compounds and colour to make it reuse into the production process [8].

Nowadays, advance oxidation process (AOP) seems to be the better solution for the treatment various industry wastewaters. It refers to chemical process, which employs oxidation techniques to degrade biologically toxic and non degradable chemicals [9]. Advance oxidation process is broadly classified into Fenton process, Photo-Fenton process, UV based process, photo catalytic redox process, sonolysis, Electro Fenton process *etc.*, The main function of this AOP is generation of highly reactive free radicals primarily hydroxy radicals, which are effective in destroying number of organic chemicals, because they are reactive electrophiles that react rapidly and non selectively [10].

Lase few decades, electrochemical advanced oxidation processes (EAOP) based on Fenton's reaction is eco-friendly method that have received much attention for industrial wastewater treatment. The most popular EAOP is the Electro-Fenton (EF) process

* Corresponding author. Tel.: +91 4294 226606; fax: +91 4294 220087.
E-mail addresses: thirusambath5@gmail.com (K. Thirugnanasambandham), drvsivakumar@yahoo.com, drvsivakumar@gmail.com (V. Sivakumar).

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[11]. Electro-Fenton process is an advanced electrochemical oxidation process based on the continuous supply of H_2O_2 generated from reaction (1) to a contaminated acid solution containing Fe^{2+} or Fe^{3+} as catalyst. •OH is then produced in the medium by the Fenton's reaction between ferrous ion and hydrogen peroxide (Eq. (3)).

$$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \quad (1)$$

$$Fe(OH)^{2+} + e^- \rightarrow Fe^{2+} + OH^- \quad (2)$$

$$Fe^{2+} + H_2O_2 + H^+ \rightarrow Fe^{3+} + H_2O + \bullet OH \quad (3)$$

This catalytic reaction is propagated from Fe^{2+} regeneration, which mainly takes place by the reduction of Fe^{3+} at the cathode (Eq. (2)). Since •OH production does not involve the use of harmful chemicals which can be hazardous for the environment, this process is environment friendly for wastewater treatment and seems to be promising for the purification of water polluted by organic pollutants. Moreover, the optimization of process variables in EF process such as initial pH, current density, H_2O_2 dose and treatment time may enhance the treatment efficiency as well as reduce the operating cost. The conventional optimization technique of changing one variable at a time to study the effects of variables on the response is time consuming and too expensive. Response surface methodology (RSM) is one of the statistical tool, which mainly used for the modeling and investigation of complex multivariable systems. The most common design under RSM is Behnken response surface design (BBD), due to the merits such as efficient and flexible, providing sufficient data on the effects of variables, overall experiment error with a minimum number of experiments [12].

An extensive literature survey shows that, there was no research reports are available on the treatment of poultry processing industry wastewater using E-Fenton process via RSM coupled with BBD. Hence, in the present study has been made to investigate the individual and interactive effect of process variables such as initial pH, current density, H_2O_2 dose and electrolysis time on the percentage removal of turbidity removal, chemical oxygen demand (COD) removal with respect to electrical energy consumption (EEC) from poultry processing industry wastewater using four factors three levels Box–Behnken response surface design (BBD). The outcome of the study will creates the novel opportunity to know the in depth knowledge of mechanism behind in EF process to treat poultry processing industry wastewater.

2. Materials and methods

2.1. Raw wastewater and chemicals

The wastewater used in this study was collected from Erode, Tamil Nadu, India and were stored at 4 °C prior to the experiments. The charcterstics of wastewater is determined and it is found to be: initial pH of 6.5, turbidity of 755 NTU, COD of 4650 mg/l and protein concentration of 5178 mg/l. All the chemicals (HCl and NaOH) used in this study were anlaytical grade and purchased from local suppliers from Erode, Tamil Nadu.

2.2. Experimental method

An working volume of 500 ml glass made beaker was used to conduct the E-Fenton experiments to treat poultry processing industry wastewater. Iron (Fe) plates were used as a anode and cathode with effective surface area of each electrode was 42 cm^2. The assembly was connected to DC power supply equipment and it was used to adjust the desired current density. In each run 400 ml of wastewater was placed into the reactor and

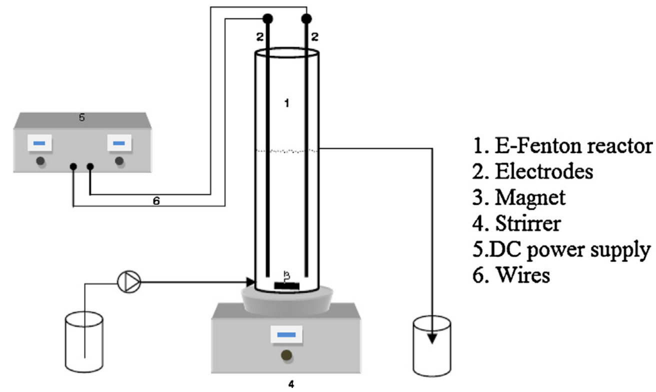

Fig. 1. Image of Electro-Fenton process experimental setup.

desired amounts of hydrogen peroxide (H_2O_2) were added. pH of the wastewater is changed with the help of 0.1 N HCl and 0.1 N NaOH. All the runs were performed at constant stirring speed of 450 rpm. After the E-Fenton treatment process, supernatant wastewater is collected and it is used to determine the reduction in turbidity and COD. Schematic diagram of E-Fenton experimental setup was shown in Fig. 1.

2.3. Analytical methods

The removal efficiency (RE) of turbidity and COD are calculated by using the following equation [13]:

$$RE = \left(\frac{c_0 - c_e}{c_0}\right) \times 100 \quad (4)$$

where, c_0 and c_e is the initial and final concentrations of turbidity and COD, respectively. The electrical energy consumption (EEC) of the present treatment process was calculated as follows [14]:

$$EEC = \frac{V I t}{V_s} \quad (5)$$

where, E is the electrical energy (kW h/l), V is the cell voltage in volt (V), I is the current in ampere (A), V_s is the volume of solution (l), and t is the time of E-Fenton process (h).

2.4. Sludge analysis

The sludge formed during the E-Fenton process was carefully decanded, weighed, and dried at 105 °C until it attained a constant weight. Then, it was used to protein digestibility test (PDT) based on method described in elsewhere [15].

2.5. Statistical experimental design

In this present study, four factors three level Box-Behnken response surface experimental design (BBD) was applied to investigate the individual and interactive effects of process variables including initial pH, current density, H_2O_2 dose and electrolysis time on the percentage removal of turbidity removal, chemical oxygen demand (COD) removal with respect to electrical energy consumption (EEC) from poultry processing industry wastewater. For statistical calculations, the process variables were coded at three levels (−1, 0 and +1) and the coding was done by the following equation [16]:

$$x_i = \frac{X_i - X_z}{\Delta X_i} \quad i = 1, 2, 3 \ldots k \quad (6)$$