Journal of Cleaner Production 172 (2018) 1089–1095

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Electrochemical treatment of wastewaters from poultry slaughtering and processing by using iron electrodes

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A R T I C L E I N F O

Article history:
Received 19 May 2017
Received in revised form
16 October 2017
Accepted 22 October 2017
Available online 27 October 2017

Keywords:
Electrocoagulation
Peroxy-electrocoagulation
Poultry slaughterhouse wastewater
COD removal

A B S T R A C T

Poultry slaughterhouse wastewater (PSWW) originating from slaughterhouse and meat processing contains high concentrations of organic substances. Discharging this kind of wastewater to a river, sewer system or soil causes a severe pollution problem for receiving body. The aim of this study was to investigate the treatability of poultry slaughterhouse wastewater using electrocoagulation method. The reactor had a cylindrical iron shell with three separate iron rods mounted vertically inside that to work as cathode and anode respectively. The effects of the current density, supporting electrolyte (Na_2SO_4) dosage, wastewater flow rate, initial pH and the polyelectrolyte material were evaluated in a continuous flow mode. The peroxy-electrocoagulation was also investigated by addition of H_2O_2 with different concentrations to reach higher removal efficiencies. When the poultry slaughter wastewater was subjected to the peroxy-electrocoagulation, chemical oxygen demand (COD) decreased to 425 mg L^{-1} from 8800 mg L^{-1} which corresponds to 95.48% of removal efficiency with an operation cost of $9 per m^3 of wastewater treated.

1. Introduction

The treatment of water and wastewater has become crucial due to and the pollution of freshwater because of discharging the not adequately treated wastewater into environment, especially in developing countries. The objectives in the wastewater treatment field has been updated from disposal to reuse and recycling because of the continuing decrease in availability of freshwater resources. Therefore, a high level of treatment efficiency has to be achieved. According to the differences in location, economic resources, living standards of different countries and characteristics of wastewater, diverse techniques may be adopted for water and wastewater treatment. Main purpose of the treatment is to remove all pollutants to a sufficient extent by selecting efficient and cost effective methods that result to a reusable water source.

Poultry slaughterhouses produce substantial amount of wastewater usually containing considerable amounts of total phosphorus (TP), total nitrogen (TN), total organic carbon (TOC), chemical oxygen demand (COD), total suspended solids (TSS), and biochemical oxygen demand (BOD) (Bustillo-Lecompte and Mehrvar, 2015; Salminen and Rintala, 2002) from different stages of processes including preprocessing, slaughtering, bleeding and scalding, further processing and evisceration, storing and packaging, poultry by-products and rendering. Poultry by-products and wastes may also contain several different species of microorganisms including potential pathogens such as Salmonella sp., Staphylococcus sp., and Clostridium sp. (Mead, 2004).

The quantity of wastewater discharged from processing operations in a poultry plant may range from 20 to 40 L per bird with 25 L being a typical value. Due to the usage of excessive amount of water, the wastewater having high concentration of pollutants is released redundantly. Depending on the desired degree of treatment, poultry wastewaters have been treated utilizing physical, chemical and biological treatment systems. Each system type possesses unique treatment advantages and operational difficulties. Among the different treatment systems, high rate anaerobic reactors have been proposed as a good alternative because of its advantages such as low initial and operational costs, smaller space requirements, high organic removal efficiency and low sludge production, combined with the production of biogas. Types of up-flow anaerobic

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https://doi.org/10.1016/j.jclepro.2017.10.254
0959-6526/

sludge blanket reactor were reported to have more than 90% COD removal efficiency from slaughterhouse wastewater in separate studies (Amin et al., 2016; Nacheva et al., 2011). A similar configuration was used under different operational conditions elsewhere (Rajakumar et al., 2011). Sunder et al. introduced an anaerobic hybrid reactor packed with special floating media and reported 89.9% COD reduction (Sunder and Satyanarayan, 2013). Some methods using anaerobic-aerobic treatment are also suggested elsewhere (Kundu et al., 2013). The main difficulty in biological treatment systems is the handling of sludge produced in huge amounts. An alternative for solving this problem are electrochemical treatment systems. The main advantages of this process are that there is usually no need of temperature and pH control since it is performed at ambient temperature and inherent pH.

Electrochemical methods such as electrocoagulation-electroflocculation and electroflotation, electroreduction, direct electrooxidation, indirect electrooxidation by using redox mediators and hydrogen peroxide (in the process known as peroxy-electrocoagulation), and photo-assisted electrochemical methods such as photo-electro-Fenton, photo-electrocatalysis have been applied for the treatment of wastewaters.

Among these methods, electrocoagulation (EC) based on in-situ formation of coagulants from a soluble anode material such as iron and/or aluminum which is oxidized due to the applied current has aroused particular interest. Simultaneous evolution of hydrogen gas at the cathode also helps the pollutants removal by flotation. A range of coagulant species and hydroxides are formed to destabilize and coagulate the suspended particles and to adsorb dissolved contaminants (Davarnejad and Sahraei, 2016).

EC process has been characterized with three successive stages (Mollah et al., 2001) as:

(i) formation of coagulants by electrolytic oxidation of the electrode
(ii) destabilization of the contaminants and particulate suspension, and breaking of emulsions
(iii) aggregation of the destabilized particles to form flocs

Electrolytic dissolution of the metallic anode produces numerous species of hydroxo metallic ion complexes which are hydrolysis products and tend to polymerize. For the iron electrode, some of the resulting polymers can be $Fe_2(OH)_2^{+4}$ and $Fe_2(OH)_4^{+5}$ (Stumm and O'Melia, 1968).

Simplified reactions for the formation of hydroxo ferric complexes in using iron anode can be shown as follows:

At acidic pH;

$$Fe \leftrightarrow Fe^{2+} + 2e^- \quad (1)$$

$$2H_2O \leftrightarrow O_2 + 4H^+ + 4e^- \quad (2)$$

$$4Fe^{2+} + 10H_2O + O_2 \leftrightarrow 4Fe(OH)_3 + 8H^+ \quad (3)$$

At alkaline pH;

$$Fe \leftrightarrow Fe^{2+} + 2e^- \quad (4)$$

$$Fe^{2+} + 2OH^- \leftrightarrow Fe(OH)_2 \quad (5)$$

Various monomeric and polymeric hydroxy complexes are then formed which act as adsorbent for the organic pollutants (Mahesh et al., 2006; Mollah et al., 2004). In some cases they can also form complexes with the organics. In a variation of the process called the peroxy-electrocoagulation, externally added hydrogen peroxide generates Fenton reactive system and synergistically works with electrocoagulation (Qiang et al., 2003; Yüksel et al., 2009). High positive charges possessing by hydroxo ferric complexes cause complexes to be adsorbed to the surface of negative particulate suspension and destabilization occurs. Interparticulate attraction makes the destabilized particles to aggregate and form readily settleable flocs. This method is characterized by simple equipment, easy operation, a shortened reactive retention period, a reduction or absence of equipment for adding chemicals and decreased amount of sludge which precipitates rapidly. This process has been shown to be an effective, reliable and environmentally compatible technology for reducing a large variety of pollutants. Moreover, during EC, the salt content of the liquid does not increase appreciably, as in the case of chemical treatment. It can be found some reports on electrochemical treatment of cattle and poultry slaughterhouse wastewater in the literature. Bayramoglu et al. reported a 93% COD removal efficiency when EC with an Al electrode was applied to poultry slaughterhouse wastewater (Bayramoglu et al., 2006). A successful hybrid process combining EC with coagulation using polyaluminium chloride resulted in 94.4% COD removal efficiency (Ün et al., 2009). In a previous work we published on a continuous plug flow reactor EC to treat cattle abattoir wastewater which resulted in 90% COD removal efficiency with an electrical energy consumption of 0.2 kWh L^{-1} (Eryuruk et al., 2014).

2. Experimental

2.1. Materials and method

The PSWW samples were obtained from a local poultry slaughterhouse in Eskisehir, Turkey. The wastewater was screened to remove hair and solids larger than 1 mm at the slaughterhouse. The electro-coagulation experimental set-up is shown in Fig. 1. The effect of various process variables such as current density (CD), supporting electrolyte (SE) concentration, flow rate, influent pH, H_2O_2 concentration and coagulant aid (PAC) concentration was investigated. These variables and the values applied for the experiments are shown in Table 1. The treatment of the poultry slaughterhouse wastewater by electrocoagulation was performed in a continuous flow operation. The plug flow electrochemical reactor was made of iron with a height of 75 cm and a diameter of 3.5 cm, and was operated as a cathode. Three iron rods (outside diameter = 1.1 cm; height = 72 cm) were used as anodes and located in the center of the cathode triangularly in plain view as can be seen in Fig. 1. Effective reactor volume was 0.675 L. The anode and cathode sets were respectively connected to the positive and negative ports of a DC power source.

Prior to each test in which the effect of pH was investigated, the pH was adjusted to a desired value using 1 N H_2SO_4 or 1 N NaOH provided from Merck in analytical grade. A specified amount of supporting electrolyte (Na_2SO_4: Merck; analytical grade) was added to the wastewater to test the effect. A sample was taken to determine the initial COD concentration and then current was applied to the circuit by a power supply (Statron T-25) for a period of 90 min. The current was held constant, pH and the conductivity of the wastewater was monitored during the experiments using a pH-meter (Hanna Ins. 301) and a conductivity meter (Radiometer Pioneer 30), respectively. Samples were taken at periodic time intervals and subjected to centrifuge and then analyzed to determine the COD by the closed reflux method according to the Standard Methods in Examination of Water and Wastewater (Association et al., 2012). All the analyses were repeated twice. The electrodes were polished with dilute H_2SO_4 and rinsed with distilled water before each run.