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Electrochemical remediation of chicken processing plant wastewater

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ABSTRACT

Chicken Processing Plant (CPP) produces a large amount of wastewater containing a variety of readily biodegradable organic compounds, carbohydrates, proteins, and fats. Experiments were conducted on the removal of pollutants from CPP wastewater using electrocoagulation (EC). Two types of EC-reactors with horizontally and vertically arranged sacrificial iron electrodes were used for this purpose. The treatment efficiency of the CPP wastewater using iron sacrificial anode was checked by changing the pH of the mixtures, EC operating time, and the current density. EC was found to be a feasible process for treating the CPP wastewater. The results showed that COD, BOD_5, fecal coliform, NH_3-N, and oil–grease can be effectively removed by EC. Treatment mechanism was discussed by characterizing EC-floc through XRD, SEM/EDS, and FTIR techniques. The BOD/COD ratio for EC treated CPP was found to be 0.53. The optimal current density was determined as 4 mAcm^{-2}. Vertical electrode assembly was more efficient to treat poultry wastewater than that of horizontal electrode assembly. EC operating time and current density have significant influences for improving removal efficiency.

1. Introduction

To overcome the drinking water crisis all over the world, it is an urgent need to explore alternative sources of water, and if possible to re-use the wastewater after proper treatment. Wastewater generated during chicken plant processing can be used as a source of water if the water is treated properly. The pollutants present in this wastewater is mostly biodegradable organics such as proteins, carbohydrates, and fats. The main contributors of organic load to these effluents are paunch, fecal, fat, undigested food, blood, suspended materials, urine, loose meat, soluble proteins, excrement, and particles [1]. Slaughterhouses generate a large volume of wastewater [2]. Most poultry processors use an average of 26.5 L of water/2.3 kg bird and this quantity ranges from 18.9 to 37.8 L/bird depending on the plant facilities [3].

There are a number of conventional parameters that characterize the pollutants in the wastewaters. The U.S. Clean Water Act (section 304(a)(4)) defines conventional pollutant parameters to include biochemical oxygen demand (BOD), total suspended solids (TSS), oil and grease, pH, and fecal coliform bacteria [4]. These pollutants are regulated by the U.S. Environmental Protection Agency (EPA). The wastewater has to be treated before it is discharged into any water drainage system or any receiving water body.

The treatment technologies available for the remediation of CPP wastewater are biological, chemical, physical, and electro-chemical processes. Biological methods are aerobic, anaerobic, and lagoon treatment. Biodegradable organics are removed by aerobic, anaerobic, lagoon, physical-chemical systems, chemical oxidation, advanced oxidation, and membrane filtration processes [5,6]. These methods have limitations in their operations. Aerobic treatment processes require high energy consumption for aeration and high sludge. Anaerobic method of poultry slaughterhouse wastewater is often sluggish or messy due to the accumulation of suspended solids and floating fats in the reactor, which lead to a reduction in the methanogenic activity and biomass wash-out. Both biological processes require long hydraulic retention time and large reactor volumes, high biomass concentration and controlling of sludge loss, to avoid the wash-out of the sludge. Even though biological processes are effective and economical, long hydraulic retention time and large area requirements make these processes less attractive than physico-chemical treatments, which require shorter retention time. Physico-chemical treatments produce large volumes of putrefactive and bulky sludge that requires special handling and further treatment [6].

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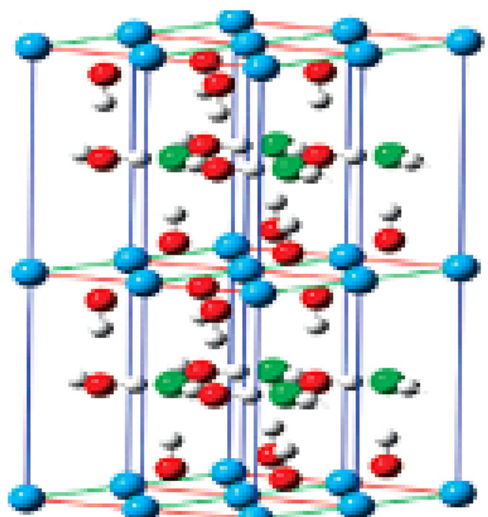

Fig. 1. Pyroaurite-type of structure consisting of alternating positively charged hydroxide layers and hydrated anion layers indicating green rust–I (GR-I) (key: blue- iron, green- chloride, red- oxygen, and white- hydrogen), reproduced after [9].

Electro-chemical techniques, such as electroflotation, electro-decantation, and EC offer the possibility to treat CPP wastewater simply and easily with the use of minimum chemicals [7,8]. EC is a promising remediation technology for treatment of poultry wastewater [9,10]. The EC process has attracted a great deal of attention in treating industrial wastewaters because of its versatility and environmental compatibility. 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 precipitate or sludge, which sediments rapidly. The process has been shown to be an effective and reliable technology that provides an environmentally compatible method for reducing a large variety of pollutants [7]. Basically, EC with iron electrodes produces intermediate byproducts, green rust (GR) as floc, and this GR is responsible for performing the remediation task. The general chemical composition and stoichiometry of GR can be represented with the following general formula: $[Fe^{II}_{(6-x)}\ Fe^{III}{}_{x}(OH)_{12}]^{x+}[(A)_{x/n}.yH_2O]^{x-}$, where x ranges from 0.9 to 4.2, A is an n-valent anion(typically $CO_3{}^{2-}$, Cl^{-}or $SO_4{}^{2-}$) and y denotes the varying amounts of interlayer water (typically y ranges from 2 to 4 for most GRs) [11,12] as depicted in Fig. 1.

The purpose of this research is to investigate the effectiveness of horizontally and vertically arranged iron electrodes in the remediation of CPP wastewater mediated by GR during EC processes. The treatment efficiency has been monitored through COD measurements, and the removal mechanisms have been recognized through floc characterization. The novelty of this study lies on the innovative engineering aspects of the EC reactor design indicating the increased efficiency of poultry wastewater treatment through electrocoagulation. The concept of green rust as a sequestration agent for water contaminants is also validated through this study.

2. Experimental

2.1. Sample collection

The CPP wastewater used in this work was collected from a local meat and poultry slaughterhouse. The samples were collected in 5 gallon plastic containers by grabbing method. While collecting the samples, head space was avoided in order to prevent oxidation by oxygen present in air. The samples were electrochemically treated within a 24 h period.

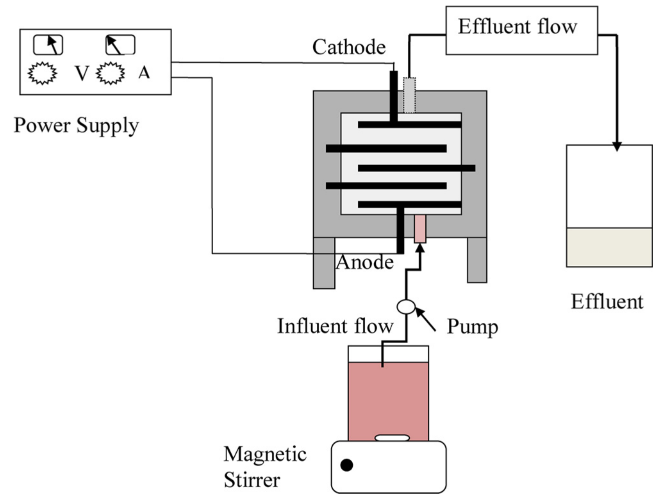

Fig. 2. Schematic diagram of EC reactor with horizontally arranged electrodes.

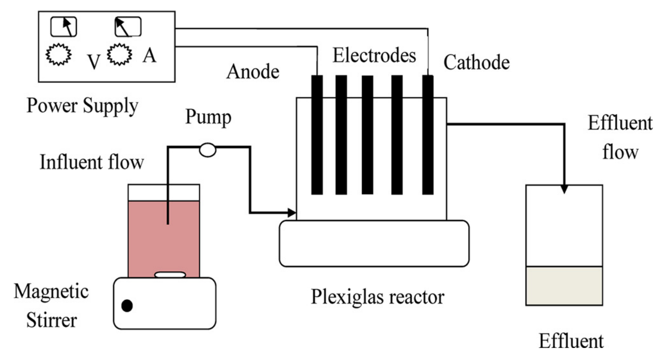

Fig. 3. Schematic diagram of EC reactor with vertically arranged electrodes.

2.2. Experimental setup

The horizontal and vertical experimental setups are shown in Figs. 2 and 3, respectively. CPP wastewater of volume 2.5 L and 3.75 L was used in horizontal and vertical continuous flow EC reactors, respectively. Five iron electrodes were used in each of the reactors. The electrodes were properly scrubbed and rinsed prior to each experiment to make their surface clean and free from passive oxide layers. The electrodes were weighed before and after EC process. These electrodes were rectangular shaped. Dimensions of horizontally arranged electrodes were 10.8 cm × 10.5 cm × 0.3 cm. Dimensions were 14 cm × 10 cm × 0.6 cm for vertically arranged electrodes. The horizontally arranged EC reactor is enclosed in corrosion-resistant material and the vertically arranged EC reactor is made of Plexiglas and is a open system. The surface area of each vertical electrode was 73 cm^2, whereas the surface area for horizontal electrode was 230 cm^2. The spacing between electrodes was 2.1 cm.

In the horizontal reactor, the electrodes are horizontally arranged, and one end was connected to anode while the other end is connected to cathode. A peristaltic pump was used to flow the water through the reactor of 500 mL volume.

In the vertical reactor, the electrodes are vertically arranged and the body of the reactor was made of Plexiglas. The volume of the vertical (Plexiglas) reactor is 1750 mL with dimensions 147 mm × 125 mm × 150 mm. The surface area of each electrode under the wastewater on which the reaction takes place was 73 cm^2.

2.3. EC experiment

The EC unit was connected to Kaselco power supply rectifier with