Journal of Environmental Management 207 (2018) 151–158

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Treatment of industrial estate wastewater by the application of electrocoagulation process using iron electrodes

Y. Yavuz*, Ü.B. Ögütveren

Anadolu University, Dept. of Environmental Engineering, Eskişehir, Turkey

ARTICLE INFO

Article history:
Received 21 June 2017
Received in revised form
21 October 2017
Accepted 12 November 2017
Available online 21 November 2017

Keywords:
Electrocoagulation
Industrial estate wastewater
Iron electrode

ABSTRACT

In this study electrocoagulation (EC) of industrial estate wastewater taken from the inlet of wastewater treatment plant was investigated using sacrificial iron electrodes. Employing a pole changer to homogenous consumption of electrodes, studies on the parameters such as current density, supporting electrolyte concentration and initial pH, which have significant effects on COD removal and hence the energy consumption, were performed. Hydrogen peroxide was used in different concentrations to observe its effects on COD removal efficiency and the energy consumption. Sludge productions were also calculated for all experiments. COD removal efficiency of ~92% was obtained at the best experimental conditions (i = 30 mA/cm^2, SE = 3 mM Na_2SO_4, pH = original pH (~6) of the wastewater, 1500 mg/L H_2O_2) with an energy cost of €3.41/m^3 wastewater treated and the sludge production of 5.45 g per g COD removed.

1. Introduction

The industrial growth and the changes in manufacturing processes have resulted in the enhancement at the volume and complexity of wastewater discharging to the environment. Many traditional and/or novel treatment processes have being modified and developed to eliminate the release of the diverse chemical substances through wastewater discharged to the receiving waters bodies. Industrial effluents may also contain toxic pollutants, which have to be reduced or eliminated to protect the environment, public health and the treatment plant in which they are treated (Araújo et al., 2005).

Main problems encountered for industrial wastewaters discharges may be hydraulic overloads, temperature extremes and excessive amounts of oil, fats and grease; acidic or alkaline constituents; suspended solids; inorganic or organic contents; explosive and flammable materials, and volatile, odorous, or corrosive gases.

In recent years there has been an increasing interest in the use of electrochemical methods for the removal of phosphate (Vasudevan et al., 2008, 2009) and boron (Vasudevan and Lakshmi, 2012) from water, arsenate (Vasudevan et al., 2010), heavy metals (Al Aji et al., 2012; Mansoorian et al., 2012; Vasudevan et al., 2012a,b) destruction of toxic and bio-refractory organic pollutants which are mainly referred to industrial wastewaters (Allen et al., 1995; Bazrafshan et al., 2012a, 2012b, 2013, 2016; Davarnejad and Sahraei, 2016; Ghatak, 2013; Koparal et al., 2007; Valero et al., 2014; Vlyssides et al., 1999; Yavuz et al., 2010). These methods use the electrons as the main reagent in a heterogeneous reaction. When ionic constituents in the wastewater are not sufficient, the use of supporting electrolyte will be required to increase the ionic conductivity. The main advantage of this process is that there is no need of temperature control since it is performed at ambient temperature. Electrochemical methods are simple, fast, inexpensive, easily operable and eco-friendly in nature. Besides, purified water is potable, clear, colorless and odorless with low sludge production. There is no chance of secondary contamination of water in these techniques (Bazrafshan et al., 2015).

Electrochemical methods such as electrocoagulation-electroflocculation and electroflotation, electro-reduction, direct electro-oxidation, indirect electro-oxidation by using redox mediators such as active chlorine and, hydrogen peroxide in the process known as electro-Fenton, and photo-assisted electrochemical methods such as photo-electro-Fenton, photo-electrocatalysis have been applying for the treatment of wastewaters.

Among these methods EC is based on in situ formation of coagulants from the sacrificial anode such as iron and/or aluminum which is oxidized due to the applied current. Simultaneous

* Corresponding author.
E-mail address: yuyavuz@anadolu.edu.tr (Y. Yavuz).

https://doi.org/10.1016/j.jenvman.2017.11.034
0301-4797/

evolution of hydrogen gas at the cathode also help remove pollutants by flotation. A range of coagulant species and hydroxides are formed to destabilize and coagulate the suspended particles and to adsorb dissolved contaminants (Mollah et al., 2001; Vasudevan and Oturan, 2014).

It is generally accepted that the EC process involves three successive stages (Joseph and Chigozie, 2014):

1. Formation of coagulants by electrolytic oxidation of the electrode
2. Destabilization of the contaminants and particulate suspension, and breaking of emulsions
3. Aggregation of the destabilized particles to form flocs

The advantages of electrocoagulation include high particulate removal efficiency, a compact treatment facility, relatively low cost, does not require supplementary addition of chemicals, reduces the volume of produced sludge and the possibility of complete automation (Bazrafshan et al., 2015; Vasudevan et al., 2008).

Oxidation of iron in an electrolytic system produces iron hydroxide, $Fe(OH)_n$, where n = 2 or 3. According to Mollah et al. (2001), two mechanisms have been proposed for the production of $Fe(OH)_n$; one of them was given below reactions and more details have been given elsewhere by Mollah et al. (2001).

Anode:

$$4Fe_{(s)} \rightarrow 4Fe^{2+}_{(aq)} + 8e^- \quad (1)$$

$$4Fe^{2+}_{(aq)} + 10H_2O_{(l)} + O_{2(g)} \rightarrow 4Fe(OH)_{3(s)} + 8H^+_{(aq)} \quad (2)$$

Cathode:

$$8H^+_{(aq)} + 8e^- \rightarrow 4H_{2(g)} \quad (3)$$

Overall:

$$4Fe_{(s)} + 10H_2O_{(l)} + O_{2(g)} \rightarrow 4Fe(OH)_{3(s)} + 4H_{2(g)} \quad (4)$$

The $Fe(OH)_{n(s)}$ formed remains in the aqueous stream as a gelatinous suspension, which can remove the pollutants from wastewater either by complexation or by electrostatic attraction, followed by coagulation (Mollah et al., 2001).

Electrolytic dissolution of the metallic anode produces the numerous species of hydroxo metallic ion complexes which are hydrolysis products, tend to polymerize. The generalized expression for these complexes is $Me_q(OH)_p^{z+}$. For 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).

Various monomeric and polymeric hydroxy complexes are then formed such as $Fe(OH)_2^+$, $Fe(HO)^{2+}$, $Fe(OH)_4^-$, $Fe(H_2O)_5(OH)^{2+}$, $Fe(H_2O)_4(OH)_2^+$, and $Fe_2(H_2O)_6(OH)_4^{4+}$ 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 EC (Qiang et al., 2003; Yuksel 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. Destabilized particles then aggregate by interparticulate attraction to form readily settleable flocs.

There are few published studies using iron electrodes for the treatment of mixed pollutants. On the contrary, most of the papers in literature are dealt with the treatment of specific industrial wastewaters. However in this study, industrial estate wastewater which was taken from the inlet of wastewater treatment plant, originating different industrial processes was examined by EC using monopolar iron electrodes. Additionally, while the parametric studies were performed, a pole changer was used to change the polarization at given time intervals for homogenous consumption of the electrodes.

2. Experimental studies

2.1. Material and methods

Parallel plate reactor, having a volume of 500 mL, consisting of three pairs of iron anode and cathode which have total anode surface area of 100 cm^2 in a parallel connection was employed in the studies. A pole changer was used between the power supply and the electrochemical reactor to use all electrodes as anode respectively.

Experimental studies were carried out at the batch mode at ambient temperature. The samples were taken at certain time intervals during the experimental runs of 60 min. After centrifugation, COD of the samples was analyzed according to the Standard Methods in Examination of Water and Wastewater (APHA-AWWA, 2012). The heavy metal concentrations were determined by ICP-OES (Varian 720 ES, Australia). Energy consumption values were also calculated using the experimental results. pH was adjusted using H_2SO_4 and NaOH when needed. Sludge was weighed for all runs to determine the amount of sludge produced per gram of COD removed and per m^3 wastewater treated in the experiments. The effects of hydrogen peroxide were also investigated. Schematic diagram of experimental set up has shown in Fig. 1.

Statron 3262.3 (0–5 A and 0–80 V) model power supply (Germany), Fluke 26 III True-rms multimeter (USA), Orion 420A model pH meter (USA), OHAUS EP214C analytical balance (Switzerland), Nuve NF800R centrifuge (Turkey), WTW Cond 720 conductivity meter (Germany), and Heidolph MR3001 model magnetic stirrer (Germany) were also used as auxiliary equipments in the experimental studies.

Wastewater provided from the inlet of Industrial Estate Wastewater Treatment Plant was used in the study. Chemical Oxygen Demand (COD), pH and electrical conductivity of the untreated wastewater have been determined in the range of 850–2100 mg/L, 5 to 7 and 1.5 to 3.5 mS/cm, respectively. All analyses were carried out in duplicate and average values have been reported.

Repeated experiments were performed with the several values of the selected parameters, which were determined after preliminary tests, as can be seen in Table 1.

3. Results and discussion

3.1. Effects of current density

Current density is the most important parameter for controlling the reaction rate within the electrochemical reactor in all electrochemical processes. The current applied to the electrochemical system determines both the amount of Fe^{2+} ions released from iron electrodes and the amount of resulting coagulants and also the bubble production rate and size (Adhoum et al., 2004; Kobya et al., 2010). The bubble size decreases with increasing current density, which is profitable to the separation process (Khosla et al., 1991). Thus, as the current density applied is increased, more Fe^{2+} ion get dissolved into the solution and the formation rate of $M(OH)_n$ is also increased (Al Aji et al., 2012). Current density values of 10, 20, 30, 40, and 50 mA/cm^2 were applied to the electrochemical reactor to examine its effect. Variations of COD removal efficiency (%), energy