Kinetic study of slaughterhouse wastewater treatment by electrocoagulation using Fe electrodes

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ABSTRACT

In this study, treatment of slaughterhouse wastewater by electrocoagulation was investigated in batch system using Fe electrodes. The effect of various variables such as electrode number, current density and operating time was tested. Pollutant removal efficiency increased with increasing electrode number and operating time. The biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solid (TSS), and total nitrogen (TN) removal efficiencies using eight electrodes at a contact time of 50 min and a current density of 10 A/m² were 66, 62, 60, and 56%, respectively. Higher electrode numbers will allow shorter operating times to achieve certain removal efficiencies. Also, removal efficiencies increased by increasing the current density; the highest removal efficiencies of BOD₅, COD, TSS, and TN at a contact time of 50 min and a current density of 25 A/m² were 97, 93, 81, and 84%, respectively. The results also show that the reactor pH varies directly with the current density; at 25 A/m², the reactor pH increased from an initial value of 7.1 to 7.7 after 50 min. The experimental results showed that the kinetics of BOD₅, COD, TSS and TN removal could be fitted adequately using a first order kinetic model (higher R²).

Key words | electrocoagulation, iron electrodes, kinetic study, slaughterhouse wastewater

INTRODUCTION

Slaughterhouse waste is defined as wastewater from an abattoir, which consists of pollutants such as animal feces, blood, and fat (US-EPA 2002). Slaughterhouse wastewater is a typical source of pollution and is a serious environmental threat (Mahataba et al. 2009). The amount of water consumption per animal slaughtered varies according to the animal and the process used and varies between 1.0 and 8.3 m³. Values of 0.4–3.1 m³ per animal were reported by Claudia et al. (2002). Slaughterhouse wastewater contains high concentrations of suspended and dissolved organic matter. Slaughterhouse wastewater treatment is performed with a static granular bed reactor (SGBR) (Al-Mutairi et al. 2004), coagulation and flocculation and UV/H₂O₂ (Cao & Mehrvar 2011). The conventional treatment method is biological treatment. Aerobic systems require large space, maintenance, management, and energy for artificial oxygenation. On the other hand, anaerobic treatment is often slow due to the accumulation of suspended solids in the reactor, which leads to a reduction in process efficiency (Masse & Masse 2000).

In recent decades, new processes for the treatment of various industrial wastewaters with low operating costs have been explored. Electrocoagulation is a treatment process based on applying an electric field which destabilizes and reduces the net surface charge on suspended and dissolved pollutants and allows for aggregation and removal by sedimentation or flotation (Emamjomeh & Sivakumar 2009). In recent years, electrocoagulation has been effective in treating paper mill effluents (Ugurlu et al. 2008), landfill leachate (Ilhan et al. 2008), olive mill wastewater (Adhoum & Monser 2004), poultry slaughterhouse and tan- nery wastewaters (Kobya et al. 2006; Jing-wei et al. 2007), textile dye wastewater (Merzouka et al. 2009).
Electrocoagulation can also remove mineral pollutants from water and wastewater, such as fluoride (Hu et al. 2005), heavy metals (Bazrafshan 2008) and nitrate (Malakootian et al. 2011). The objective of this study was to evaluate the efficiency of electrocoagulation on the removal of pollutants from slaughterhouse wastewater using Fe electrodes by systematically testing the effects of electrode number, operating time, and current density.

METHODS

Instruments

The electrocoagulation reactor is shown in Figure 1. The reactor consisted of an electrocoagulation cell (14 x 12 x 10 cm) made of Plexiglas with the cathode and anode in parallel mode. All electrodes were 2.0 mm-thick iron sheets with a total effective electrode area of 75 cm². The electrodes were connected to a DC power supply providing a current density in the range of 5–25 A/m² in monopolar connection.

Wastewater characteristics

Wastewater samples were obtained from a slaughterhouse located in the city of Kermanshah, Iran. At the slaughterhouse, samples were passed through a 1 mm sieve to remove hair and large suspended solids. Samples were then conveyed to the laboratory in about 1 h and stored at 4 °C before starting the experiments. The main characteristics of the raw slaughterhouse wastewater used in this study were pH: 7.1 ± 0.3; 5-day biochemical oxygen demand (BOD₅) 2,060 ± 429; chemical oxygen demand (COD) 2,770 ± 537; total suspended solids (TSS) 3,130 ± 541 and total nitrogen (TN) 101 ± 26 mg/L.

Test methods

The electrocoagulation of slaughterhouse wastewater was investigated in batch system. The effect of electrode number, operating time and current density were investigated. All experiments were conducted at room temperature. The volume of the wastewater in each run was 1 L and the magnetic stirrer was adjusted to 250 rpm. At the end of each run, the sample was filtered through a 0.45 μm paper filter and the filtrate was analyzed. Also, pH changes during the electrocoagulation process were evaluated.

Analysis

Analyses of slaughterhouse wastewater including BOD₅, COD, TSS and TN were carried out according to the standard methods for examination of water and wastewater (APHA 1992). The pH was measured by a Hanna Instruments pH meter. The COD and nitrogen contents were analyzed with a Hach DR 2,500 Odyssey spectrophotometer. SPSS software was also used for data analyzed and also, the variance test (one-way ANOVA) for comparison of means, and paired t-test for determination of association between parameters.

RESULT AND DISCUSSION

Effect of electrode number and contact time

The effect of electrode number on BOD₅, COD, TSS and TN removal is shown in Figure 2. BOD₅, COD, TSS and TN removal increased with increasing electrode number and contact time reaching 66, 62, 60 and 54% removal with
eight electrodes after 50 min (current density: 10 A/m²), respectively, and BOD₅, COD, TSS and TN concentration decreased from 2,060 ± 429, 2,770 ± 537, 3,130 ± 541 and 101 ± 26 mg/L to 700 ± 183, 1,052 ± 206, 1,252 ± 216 and 47 ± 12 mg/L, respectively. The association between contact time and BOD₅, COD, TSS and TN removal efficiency, analyzed with paired t-test, was statistically significant (P-value < 0.001). Also results of the one way ANOVA showed that the association between different electrode number (four, six and eight electrodes) was statistically significant (P-value < 0.001).

The mechanism of the electrocoagulation process in aqueous systems is inherently complex. It is generally believed that there are two possible mechanisms involved in the process: electro-flotation and electro-oxidation. Oxidation and reduction of the electrochemical process occur at the anode and cathode electrodes, respectively (Emamjomeh & Sivakumar 2009). Generally, the resistivity of the electrode is inversely proportional to the cross-sectional area. Higher cross-section area of the electrode provides lower electrode resistivity, so electricity conductivity increases during the electrocoagulation reaction. The results show that, with increasing electrode number, pollutant removal efficiency increases. This finding can be due to more consumption of energy, neutralization of surface charges, and production of more flocs in a shorter time. These results have also been confirmed by other studies (Malakootian et al. 2011). In the electrocoagulation process, dispersed organic particles are aggregated into large flocs and separated from the liquid phase by sedimentation (Emamjomeh & Sivakumar 2009). With increasing contact time, sedimentation increases due to increased flocs size with time (Niam et al. 2007). This result is confirmed by Jing-wei et al. (2007) for treatment of tannery wastewater by electrocoagulation.

**Effect of applied current density**

Figure 3 shows that BOD₅, COD, TSS and TN removal increased with current density, reaching 97, 93, 81 and 84% removal at 25 A/m² at a contact time of 50 min, respectively. The BOD₅, COD, TSS and TN concentration decreased from 2,060 ± 429, 2,770 ± 537, 3,130 ± 541 and 101 ± 26 mg/L to 62 ± 13, 194 ± 38, 595 ± 103 and 17 ± 4 mg/L, respectively. The association between current density and BOD₅, COD, TSS and TN removal efficiency was analyzed with paired t-test and was shown to be statistically significant (P-value < 0.001). Also, results of the one way ANOVA show that the association between different
applied current density (5, 10, 15, 20 and 25 A/m²) is statistically significant ($P$-value < 0.001).

Current density is the most important parameter for controlling the reaction rate in the electrocoagulation processes because it determines the coagulant dosage, whether in batch or continuous mode. The amount of coagulated ions released from the sacrificial anode into solution is directly affected by the current density. The results of this study show that, with increasing current density, pollutant removal efficiency increased. Increasing the removal efficiency by increasing the current density increases the charge loading. As charge loading increases, the result is greater flocculation and faster sedimentation of pollutants (Yetilmezsoy et al. 2013). This result concurs with results of Kobya et al. (2009) for treatment of poultry slaughterhouse wastewater by electrocoagulation.

An improvement in electrocoagulation performance with an increase in current density can be explained by taking into consideration Faraday's law and the scarification of the anode, and hence coagulant generation (Aoudj et al. 2010; Malakootian et al. 2011). Faraday's law describes the relationship between current density and the amount of anode material that goes into the solution:

$$w = \frac{itM}{ZF}$$

where $w$: transpose anode and dissolving (g/cm²), $i$: current density (A/cm²), $t$: contact time (s), $M$: molecular weight of anode material, $Z$: number of electrons involved in the oxidation/reduction reaction and $F$: Faraday's constant (=96,487 C/eq). In order to avoid excessive energy consumption, the current density should be chosen based on optimum pollutant removal efficiency (Emamjomeh & Sivakumar 2009).

**The effect of electrocoagulation on pH**

The effect of electrocoagulation on the wastewater pH is shown in Figure 4. The pH increased gradually with contact time and this increase was greater at the higher current densities.

The electrocoagulation process is highly dependent on solution pH (Malakootian et al. 2011). This study showed that the pH of the wastewater increased during the electrocoagulation process and the pH increased the most at the
higher current densities. This increase depends on the activity of anode and cathode during the electrocoagulation process and is dominated by the cathode. The increase of pH is attributed to hydrogen gas and OH⁻ formation at the cathode (Bazrafshan 2008). Generally, variations in pH during the electrocoagulation process depend on the type of electrodes and the initial pH (Malakootian et al. 2011). In this study, the pH increased from 7.1 to 7.7. Ilhan et al. (2008) have reported similar results for treatment of leachate by electrocoagulation process.

### Kinetic study of electrocoagulation process

All processes related to purification of water and wastewater are done in a volume; this volume is called the reactor. Variations in the combination and concentration of materials in the reactor are the main factors in the purification of water and wastewater. These variations result from hydraulic transfer of materials into and out of the reactor as well as from reactions within the reactor. To completely describe a reactor system and its design, reaction rates that occur in the reactor must be specified as these rates directly affect reactor size. Therefore, the study of reaction kinetics to predict pollutant removal rates is very important in designing and modeling the treatment process (Tchobanoglous et al. 2003).

The kinetics of the electrocoagulation BOD₅, COD, TSS and TN removal reaction needs to be examined for estimating the time required for BOD₅, COD, TSS and TN removal. A kinetic analysis was conducted by fitting the time-course performance data with zero, first, and pseudo-second order kinetic equations and calculations as shown in Table 1 where \( r_c \) is the rate of conversion, \( k_0, k_1, \) and \( k_2 \) are reaction rate coefficients, \( t \) is time, and \( C \) is the final concentration of the constituent in the liquid. The reaction

| Parameter | Current density (A/m²) | Zero order |                   |                   |                   |                   |                   |                   |
|-----------|------------------------|------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|           |                        | \( r_c = \frac{dC}{dt} = k_0 \) |                   |                   |                   |                   |                   |
| BOD₅      | 5                      | 21.69      | 0.94              |                   |                   |                   |                   |
|           | 10                     | 25.98      | 0.91              |                   |                   |                   |                   |
|           | 15                     | 30.97      | 0.92              |                   |                   |                   |                   |
|           | 20                     | 34.38      | 0.89              |                   |                   |                   |                   |
|           | 25                     | 36.06      | 0.87              |                   |                   |                   |                   |
| COD       | 5                      | 27.16      | 0.96              |                   |                   |                   |                   |
|           | 10                     | 31.06      | 0.98              |                   |                   |                   |                   |
|           | 15                     | 36.65      | 0.92              |                   |                   |                   |                   |
|           | 20                     | 39.77      | 0.90              |                   |                   |                   |                   |
|           | 25                     | 47.48      | 0.92              |                   |                   |                   |                   |
| TSS       | 5                      | 32.98      | 0.98              |                   |                   |                   |                   |
|           | 10                     | 38.51      | 0.95              |                   |                   |                   |                   |
|           | 15                     | 42.33      | 0.93              |                   |                   |                   |                   |
|           | 20                     | 43.65      | 0.91              |                   |                   |                   |                   |
|           | 25                     | 47.64      | 0.87              |                   |                   |                   |                   |
| TN        | 5                      | 0.89       | 0.93              |                   |                   |                   |                   |
|           | 10                     | 1.04       | 0.87              |                   |                   |                   |                   |
|           | 15                     | 1.25       | 0.91              |                   |                   |                   |                   |
|           | 20                     | 1.37       | 0.89              |                   |                   |                   |                   |
|           | 25                     | 1.47       | 0.89              |                   |                   |                   |                   |
rate coefficients and $R^2$ values for each pollutant category and current density are also summarized in Table 1.

The data were correlated well (higher $R^2$) by the first order kinetic model, revealing the model can successfully simulate the BOD$_5$, COD, TSS and TN removal in the electrocoagulation at different current densities. According to Table 1, the first order kinetic constant increased when the applied current density was increased from 5 to 25 A/m$^2$. The results of kinetic evaluation of the treatment of slaughterhouse wastewater by electrocoagulation is in agreement with the results obtained by Mameri et al. (2003) in a bipolar electrocoagulation reactor and by Emamjomeh & Sivakumar (2006) in a monopolar electrocoagulation reactor.

According to Asselin et al. (2008) electrochemical coagulation operated under the optimal conditions involves a total cost of US$0.71 per cubic metre and Masse & Masse (2000) stated that overall slaughterhouse treatment cost in 1995–1996 ranged from US$0.70 to US$1.60 per cubic metre of wastewater.

**CONCLUSION**

In this research work, the treatment of slaughterhouse wastewater by electrocoagulation was investigated in batch system using iron electrodes. This study has shown that application of higher current density and longer operation time enhances removal efficiencies of BOD$_5$, COD, TSS and TN. It also indicated that the reactor pH varies directly with the current density. The experimental results showed that the kinetics of BOD$_5$, COD, TSS and TN removal could be fitted adequately using a first order kinetic model (higher $R^2$). This study showed that electrocoagulation is an efficient technology for the treatment of slaughterhouse wastewater.

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**REFERENCES**


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