

Investigation of the Effectiveness of Electrooxidation for the Treatment of Domestic Wastewater

Alper Erdem Yilmaz¹, Onur Sozudogru¹, Theoni Massara^{2,3}, Evina Katsou^{2,3}, Okan Tarik Komesli¹

¹Department of Environmental Engineering, Faculty of Engineering, Ataturk University, 25240, Erzurum, Turkey.

²Institute of Environment, Health and Societies, Brunel University London, Uxbridge Campus, Middlesex, UB8 3PH, Uxbridge, UK.

³Department of Civil and Environmental Engineering, Brunel University London, Uxbridge Campus, Middlesex, UB8 3PH, Uxbridge, UK.

Corresponding author:

A.E. Yilmaz (aerdem@atauni.edu.tr);

Tel.: ++90 4422314799;

Department of Environmental Engineering, Faculty of Engineering, Ataturk University, 25240, Erzurum, Turkey.

Abstract

In this study, the lab-scale removal of chemical oxygen demand (COD) from domestic wastewater was investigated by implementing the electrooxidation (EO) process. Titanium and stainless-steel electrodes were used as anode and cathode, respectively. The effect of changing key process parameters such as the wastewater initial pH and the current value was examined. It was noted that the COD removal was improved after increasing the initial wastewater pH. The change in the applied current value was also defined as an important parameter since it impacts on the intensity of the chemical oxidation. According to the obtained results, the optimal COD removal (i.e. 84.7%) was achieved for an initial wastewater pH equal to 9 and for a current of 20 A. For an initial wastewater pH of 9, COD removal was found to be equal to 64%, 77% and 84.7%, at 10A, 15A and 20A, respectively. On the contrary, lowering the initial wastewater pH to 3 resulted in a significantly poorer system performance with the COD removal being equal to 49%, 64.6% and 64.7% at 10A, 15A and 20A, respectively. Overall, the EO process can stand as an effective alternative method for domestic wastewater treatment due its simple installation and operation, and its potential to achieve high COD removal.

Keywords: Electrooxidation, wastewater initial pH, current, domestic wastewater

1. Introduction

Electrochemistry is an important field of science that includes all the redox reactions which happen by using electrical energy [1]. The processes of coagulation, adsorption, absorption, precipitation and flotation belong to the wide group of electrochemical treatment [2]. The most significant differential parameters among them refer to the shape and structure of the process (e.g. electrode type, applied current, electrical voltage, etc.) [3]. Nowadays, the electrochemical treatment methods are widely used for domestic and industrial wastewater treatment since they are simple to operate and highly efficient. Under slight variations, several electrochemical methods (e.g. electrocoagulation, electrodialysis, electroflotation and electrooxidation (EO)) are now used worldwide for industrial applications [4]. EO is the most popular electrochemical treatment variation because of its high efficiency combined with minimized sludge formation. The simple EO principle is to (directly or indirectly) achieve the desired oxidation with the gases (O_2 and H_2) released by using the non-melting electrodes [5-6]. In the direct anodic oxidation, the first step is the pollutants to be adsorbed onto the anode surface. The second step is the electron transfer occurring from the anode surface [7-9]. As far as the indirect EO process is concerned, intermediates such as Cl_2 [10], $HOCl$ [11] and H_2O_2 [12] are likely to be placed on the anode surface and, thus, affect the oxidation of organic materials [13-14]. Fig. 1 shows schematically the direct and indirect EO.

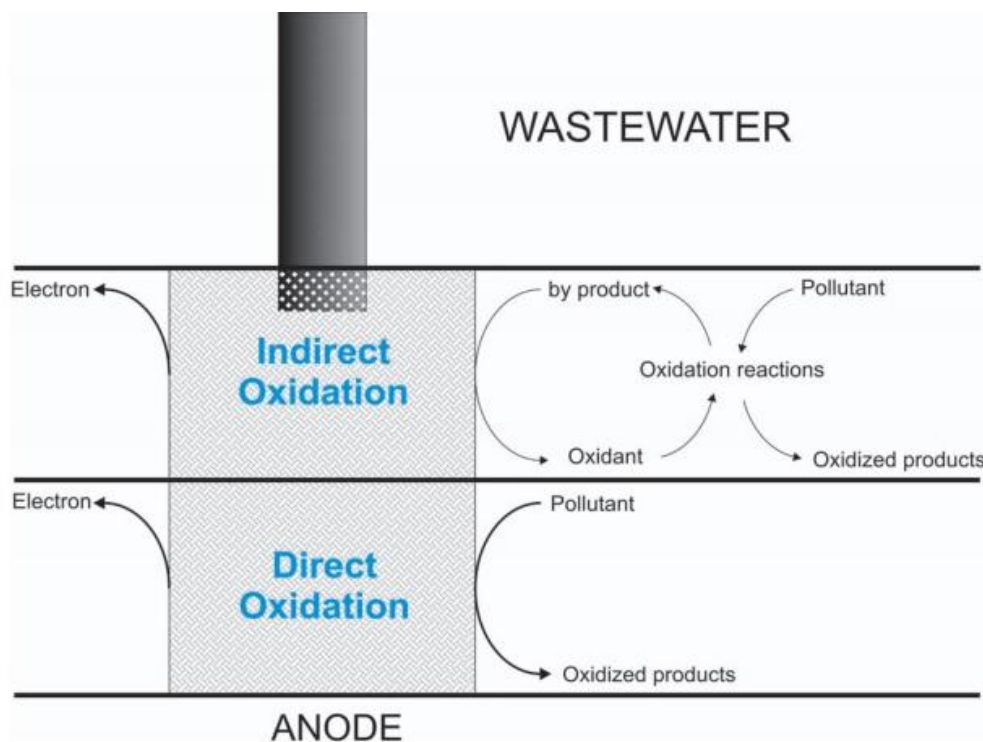


Figure 1. Schematic representation of the direct and indirect EO process.

In the EO process, the anode plays an active role. For this reason, the catalytic activity is the most influential aspect. During the EO, the target pollutant is removed by the aid of the ($\cdot\text{OH}$) generated in the anode (see reaction 1) [15-17]. Then, the ($\cdot\text{OH}$) formed on the anode surface react with the organics (see reaction 2) [17-19].



The wastewater initial pH is a highly important parameter due its effect on the electrolytic reactions taking place. During the formation of ($\cdot\text{OH}$) radicals, pH is the first parameter to be affected and possibly changed because of the occurring reactions. In the present study, the effectiveness of EO in treating domestic water was investigated at lab-scale. The chemical oxygen demand (COD) removal from domestic wastewater was examined under the effect of changing key process parameters including the wastewater initial pH and the applied current.

2. Materials and methods

The wastewater used in this study was taken from a storm drain in the Ataturk University Campus Area (Erzurum, turkey). The experiments were carried out in a continuous electrolytic cell made of glass [5 cm (radius) \times 15 cm (height)]. Five stainless-steel and five titanium (Ti) electrodes were used as cathode and anode, respectively, with a surface area of 2600 cm². The properties of the Ti anode material are given in Table 1. 2 L of real domestic wastewater were utilized in all experiments. The electric power was provided by a lab DC power supply (Chorome 62024P-40-120). At the beginning of each set of experiments, the pH of the wastewater was adjusted to the preferred value by adding 0.1 M H₂SO₄ and 0.1 M NaOH. The characterization of the domestic wastewater used in this work is presented in Table 2.

Table 1. Properties of the Ti anode material.

Electrode potential	0.20 V
Ionic radius	0.680 Å
Electro negativity	1.54
Electrochemical equivalent	0.4468 g A ⁻¹ h ⁻¹
Density	4.5 g cm ⁻³
Melting point	1,650-1,670 °C

Boiling point	3,287 °C
Tensile strength	220 MPa
Modulus of elasticity	116 GPa
Properties Metric Imperial Thermal Expansion Coefficient (20-100°C/68-212°F)	8.90 $\mu\text{m m}^{-1} \text{ }^\circ\text{C}^{-1}$
Thermal conductivity	17 W mK ⁻¹

Table 2. The characterization of the domestic wastewater used in the present study.

COD	[mg L ⁻¹]	900-1,150
BOD	[mg L ⁻¹]	95-210
Specific conductivity	[$\mu\text{S cm}^{-1}$]	665-1,230
Turbidity	[NTU]	59.2-170
pH	[-]	3.05, 5.02, 7.07, 9.02

The COD analysis was performed according to the 5220C Standard Method. Electric current and pH were measured throughout the study using specific probes (WTW Multi 3401). The COD removal efficiency was calculated as follows:

$$\text{Removal efficiency (\%)} = \frac{C_0 - C_t}{C_0} \times 100 \text{ (Equation 1)}$$

Where C_0 is the initial COD value (mg L⁻¹), C_t is the COD value at time t .

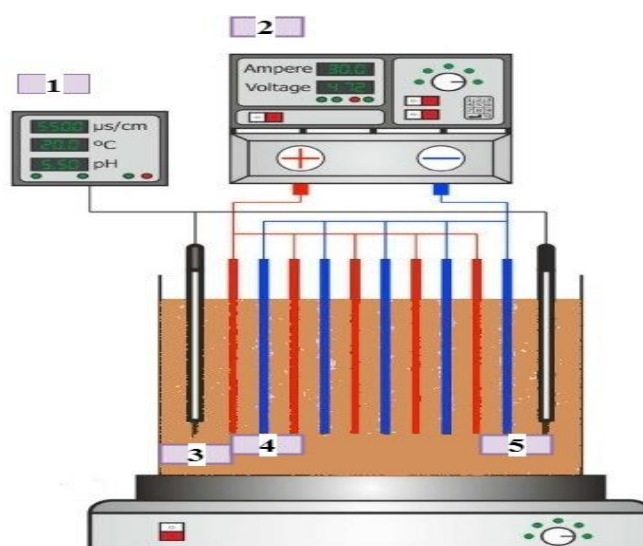


Figure 2. Schematic diagram of the experiment setup; 1: Multiparameter, 2: DC power supply, 3: Wastewater, 4: Ti anode electrode, 5: Steel cathode electrode.

3. Results and Discussion

Three sets of experiments were performed to examine the effect of different values for the initial wastewater pH (3, 5, 7 and 9) with a different current value applied each time: i.e. 10, 15 and 20 A. The samples were taken and measured in terms of COD removal after 120 min. The results are shown in Fig. 3.1, 3.2 and 3.3 for the current values of 10, 15 and 20 A, respectively.

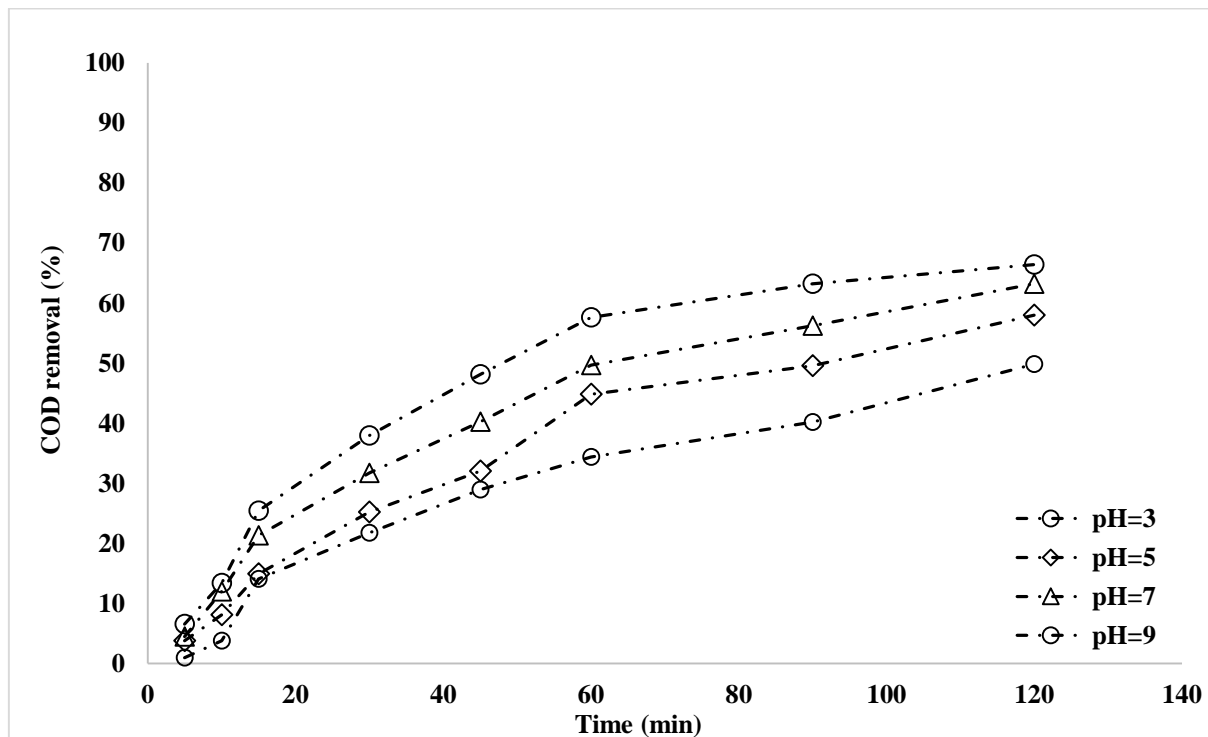


Figure 3.1. The effect of different initial wastewater pH values on the COD removal. The applied current was 10 A.

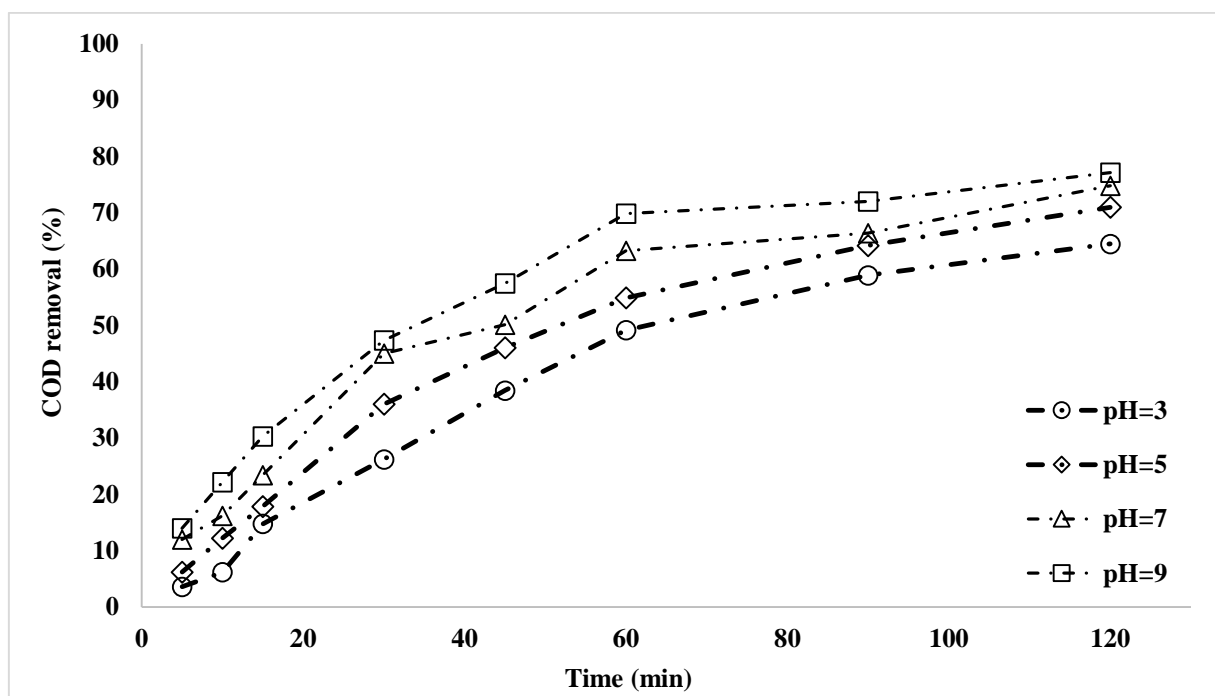


Figure 3.2. The effect of different initial wastewater pH values on the COD removal. The applied current was 15

A.

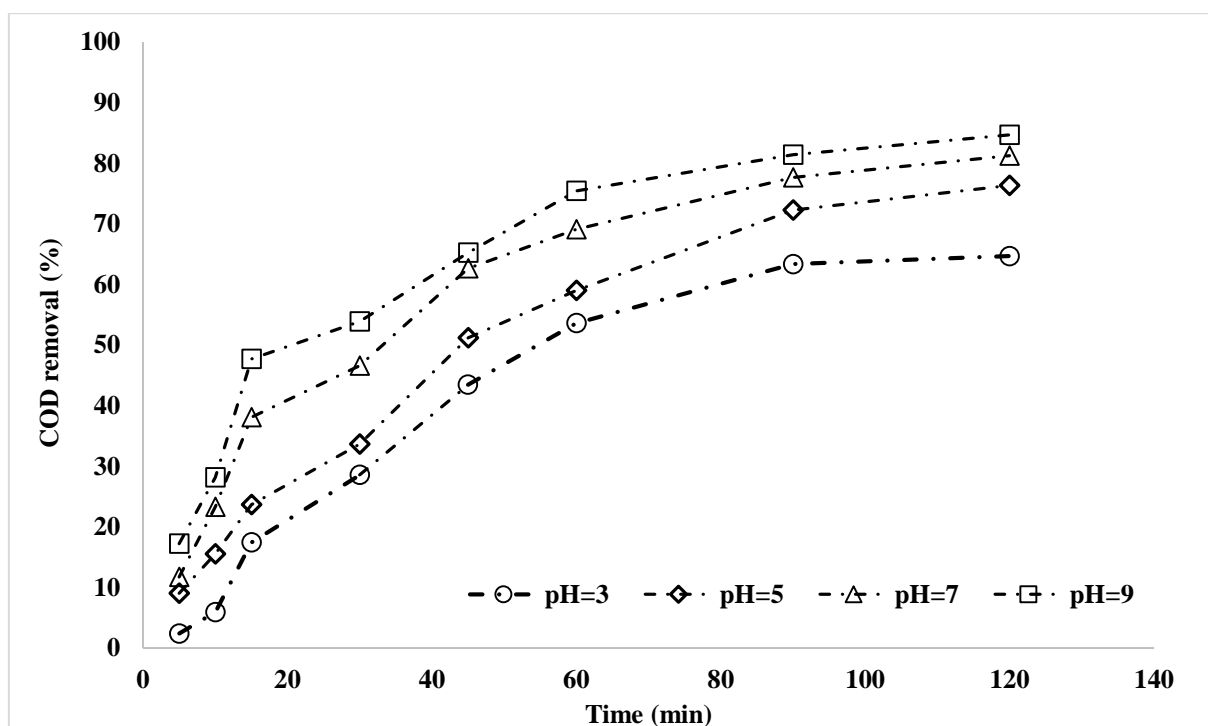


Figure 3.3. The effect of different initial wastewater pH values on the COD removal. The applied current was 20

A.

During the EO, the removal efficiency generally depends on the initial wastewater pH value as well as on the pH variation whilst the process is happening [20]. More importantly, it has been showed that the COD removal can rise after increasing the pH and the current intensity; e.g. Gotsi et al. [21] observed an improvement in the COD removal following the pH increase from 5 to 9 after applying EO for the treatment of olive mill wastewater. By increasing the pH, the formation of ($\cdot\text{OH}$) radicals in the solution is enhanced; the latter significantly ameliorates the EO efficiency (see reaction 2) [22-23]. Nevertheless, the pH effect becomes minor beyond the pH range of 3-10 [21-13]. As seen in Fig 3.1 (current=10 A), a COD removal of 49% was noted for a pH=3, rising to 66% at pH= 9. As current and pH increased (Fig. 3.2 and 3.3), better COD removals were attained. At 15 A and 20 A, COD was removed by 77.1% and 84.7%, respectively, at the highest pH applied (i.e. 9). Similar past studies have also supported that the pollutant degradation rate can significantly increase with the current density increase [24-25].

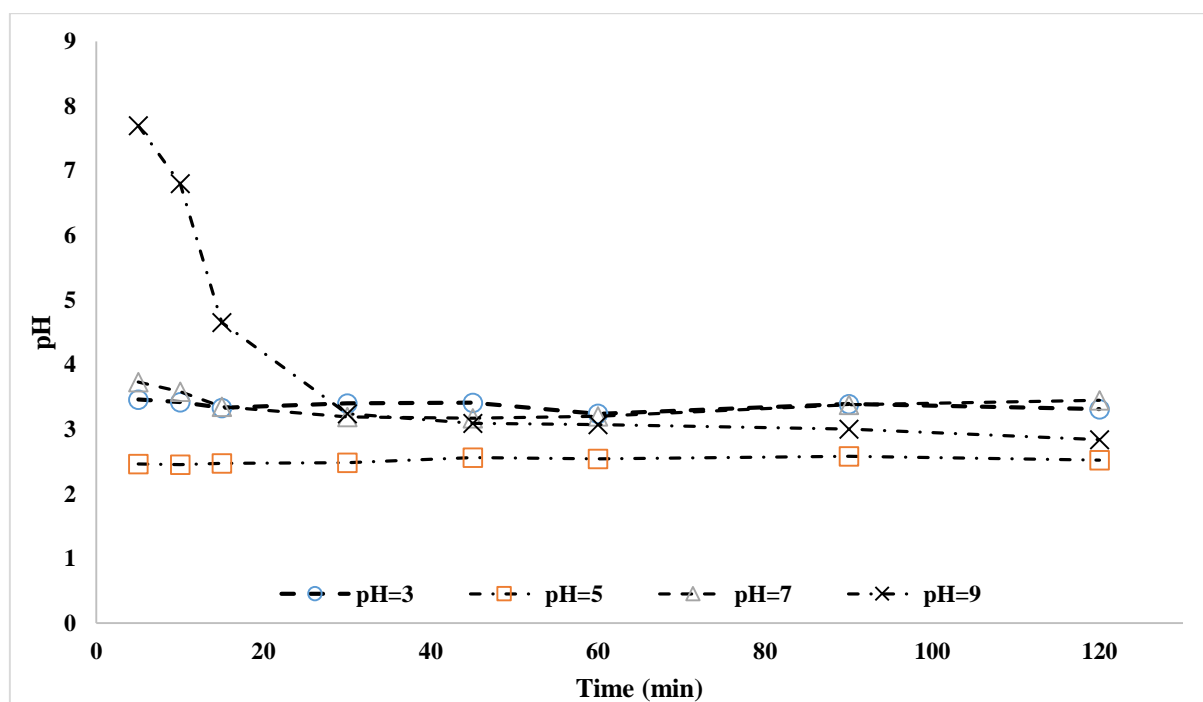


Figure 3.4. The variations in the pH whilst the EO was taking place for the each one of the different initial wastewater pH values applied (current=20 A).

As shown in Fig. 3.4, pH was found to generally decrease during the EO process, independently of how high the initial wastewater applied value was. At the end of the 120-min reaction period, the effluent pH was 3.5 for the

initial wastewater pH value of 9, and 2.5 for the initial wastewater pH value of 5. Acidic conditions appeared just after the first 10 min of the reaction for all initial pH values and persisted until the end of the reaction time. The COD removal increased with the increasing acidic conditions. However, after carefully examining Fig. 3.4, it appears that the best removal was achieved under weak acidic conditions, not strong ones.

4. Conclusions

The results of this lab-scale study on the effects of the initial wastewater pH and current value on the treatment of domestic wastewater by applying the EO process can be summarized as follows:

1. The initial pH value of the wastewater has a significant effect on the COD removal. By increasing the initial pH value, the COD removal was improved at the end of the reaction time. This increase also caused the effluent pH value at the end of the reaction period to remain under weak acidic conditions.
2. The change in the applied current value was also defined as an important parameter since it impacts on the intensity of the chemical oxidation. Increasing the current from 10 A to 20 A resulted in an increase in the COD removal, as well as in a decrease of the effluent pH values.

Overall, the EO process can stand as an effective alternative method for domestic wastewater treatment due its simple installation and operation, and its potential to achieve high COD removal.

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