Applications of electrochemical treatment for domestic wastewater

A. E. Yilmaz[1], T.M. Massara[2,3], O. T. Komesli[1], E. Katsou[2,3]

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

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

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

Corresponding author:

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

Tel.: ++90 4422314799;

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

Abstract

In this study, the treatment of domestic wastewater from the city of Erzurum (Turkey) was investigated by applying the electrocoagulation treatment process. Aluminum electrodes as anode and stainless-steel plate electrodes as cathode were placed in the electrocoagulation jacketed reactor where the batch experiments took place. The wastewater initial pH value was selected as the key process parameter whose impact on the system's removal efficiency was studied. The reaction time was chosen to be equal to 30 min and the current was set at 10 A. The effect of the wastewater initial pH value was examined by arranging the pH to vary from 5 to 7.8. The optimal COD removal was obtained at the original pH value of the influent (i.e. 7.8). Decreasing the initial wastewater pH value from 7.8 to 5 resulted in reducing the system's removal efficiency. Under the 10 A constant current value and the reaction time of 30 min, COD removal of 87% was noted for an initial pH value of 7.8 dropping at only 55% as the initial pH value reached the value of 5. The obtained results showed that the electrocoagulation process can be an effective process for domestic wastewater treatment after investigating the optimization of key process parameters (e.g. initial wastewater pH value).

Keywords: Domestic wastewater, electrocoagulation, wastewater initial pH, optimization of key process parameters

1. Introduction

Nowadays, the restrictions on the availability of water resources and the severe environmental impact of inadequately treated wastewater on planetary health are an undeniable worldwide concern. Finding ways to mitigate water pollution and enhance water recycling is amongst the greatest environmental problems of the 21st century [1]. In this context, water treatment technologies are emerging as the most direct solution to reduce pollution in water bodies. Hence, central water and wastewater treatment facilities are working towards this direction. The physico-chemical wastewater treatment processes, in particular, are quite popular; they have been known and practiced for years to produce water effluents able to meet human needs [2]. However, the target pollutants in wastewater are highly variable over time and in terms of quantity because of the recent technological developments and extended industrialization. Thus, the optimization of water treatment technologies has now become a very important research topic.

Urban wastewater treatment plants are generally effective in reducing the organic matter, nitrogen and phosphorus content of urban wastewater. However, there has been a serious decrease in the water availability over the last years due to the increase in water demand and the intensive use of the already scarce water resources. For this reason, not only the treatment but also the reuse of wastewater is a matter of great interest for the elimination of water stress [3-6].

The electrocoagulation is a wastewater treatment process that involves the application of electric current across metal electrodes to remove various contaminants. It is a reliable method with both environmental and economic benefits [7], that has been successfully applied for the removal of various pollutants from wastewater effluents including toxic metals [8], oil mill wastewater [9], arsenic [10-11], and chemical oxygen demand (COD) [12]. Furthermore, the electrocoagulation has been reported to effectively treat drinking water [13-14], fluoride [15], and metal plating wastewater [16].

In this study, domestic wastewater was treated with aluminum electrodes (anode) and stainless-steel plate electrodes (cathode) placed in a lab-scale electrocoagulation jacketed reactor where batch experiments took place. The effect of key process parameters such as the initial wastewater pH value was investigated in terms of COD removal.

2. Materials and Methods

In this work, domestic wastewater from the city of Erzurum (Turkey) was used. It had the following characteristics: COD=250 mg L^{-1}, biological oxygen demand (BOD_5)=175 mg L^{-1}, suspended solids (SS)=80-100 mg L^{-1}, conductivity=1,000-1,050 μS cm^{-1}, and temperature=15±3 °C. In the batch electrocoagulation system, a rectangular reactor with total volume of 1 L was used with 7 stainless-steel electrodes (cathode) and 7 aluminum electrodes (anode). The distance between the electrodes was 5 mm and their total surface area 2,400 cm^2. A Chroma brand digitally controlled direct current power supply (62024P–40–120 model, 0-40 V, 1-120 A) was installed to provide power. A wastewater brand multi-meter was used to adjust the pH, conductivity and temperature of the wastewater in the beginning of the reaction, as well as to instantly read their values while the reaction was happening. In this study, the initial pH value of the wastewater was examined as key process parameters in terms of its effect on the lab-scale system performance. The experimental set-up is given in Fig. 1.

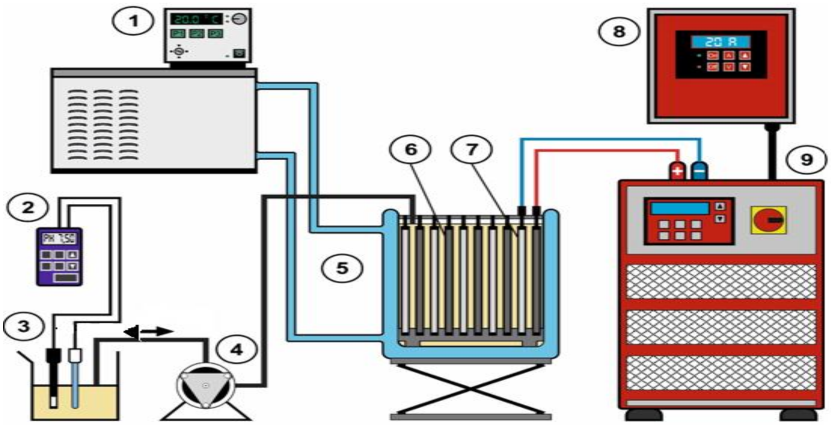

Figure 1. Experimental setup: 1: circulator, 2: multimeter, 3: pH control cell, 4: peristaltic pump, 5: reactor, 6: anode electrode (aluminum), 7: cathode electrode (stainless-steel), 8: control panel, 9: power supply.

The COD analyses were conducted according to the closed system (reflux) method as specified in the standard methods [17]. The following equations were used for calculating the treatment efficiency and energy consumption of the system out of the experimental data:

Equation 1: calculation of the treatment efficiency

$$\eta(\%) = \left(\frac{C_0 - C_e}{C_0} \right) x100 \qquad (1)$$

C_0: initial pollutant concentration (mg L^{-1}); C_e: the remaining concentration of the pollutant in the wastewater at time t (mg L^{-1}).

Equation 2: calculation of the system's energy consumption

$$W\left(\frac{kW-h}{m^3}\right) = \frac{V*I*t}{\vartheta} \qquad (2)$$

W: energy consumption (kW-h m^{-3}), I: applied current (A), V: potential difference in the system (V), t: reaction time (min), ϑ: total wastewater volume (m^3).

3. Results and Discussion

During wastewater treatment by means of the electrocoagulation method, the wastewater initial pH plays a very important role and significantly affects the treatment efficiency. To examine effect of this key process parameter on the COD removal, four different pH values were applied: 5, 6, 7 and 7.8 (i.e. the natural initial pH of the wastewater). Nitric acid (HNO_3) solutions were used to adjust the initial wastewater pH to the desired value when needed (i.e. for the values of 5, 6 and 7). The current was kept constant at 10 A and the retention time at 30 min. Samples were taken from the reactor at the 5^{th}, 10^{th}, 15^{th}, 20^{th} and 30^{th} (i.e. final) min of the reaction. COD, effluent pH value, temperature, and electrical conductivity were determined by the aid of these samples. The effect of different initial wastewater pH values on the system's COD removal is shown in Fig. 2.

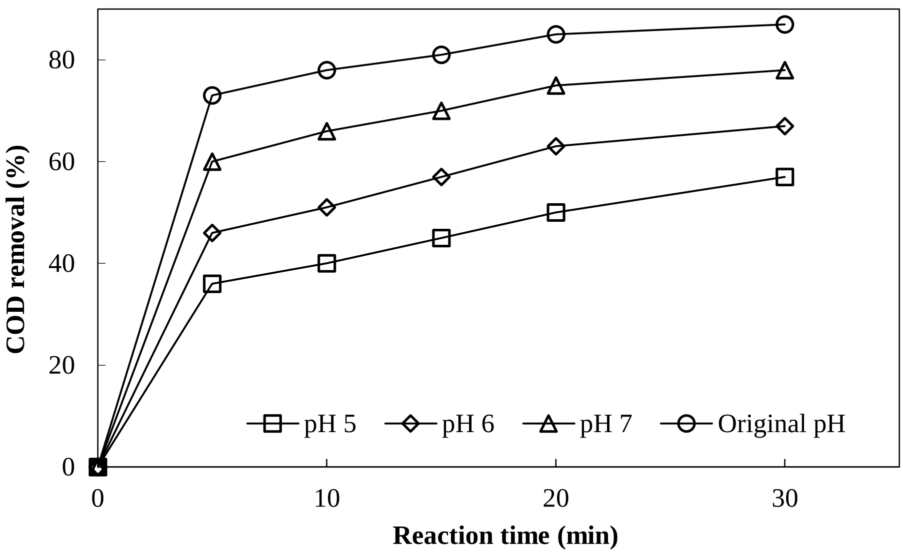

Figure 2. The effect of the initial wastewater pH value on the COD removal. The current was kept constant at 10 A and the retention time at 30 min.

It can be seen that the highest COD removal (≈87%) was obtained at the original wastewater pH value (i.e. 7.8). On the contrary, the lowest COD removal (≈55%) was noted for an initial wastewater pH value of 5; it was around 77% and 60% for the initial pH values of 6 and 7, respectively. It is essential to examine the pH values of the medium and COD removal during the first 5 min of the reaction so that this can be explained. The pH values appearing just after the first 5 min of the reaction are 5.8, 6.3, 6.8 and 7.3 for an initial wastewater pH of 5, 6, 7 and 7.8, respectively, corresponding to COD removals of 35%, 45%, 60% and 70%. The pH range at which the solubility of the coagulant (i.e. aluminum hydroxide ($Al(OH)_3$)) is the lowest is between 6.5 and 8 [18]. Thus, when the medium pH remains within this range, the condition for pollutant precipitation via coagulation is optimal.

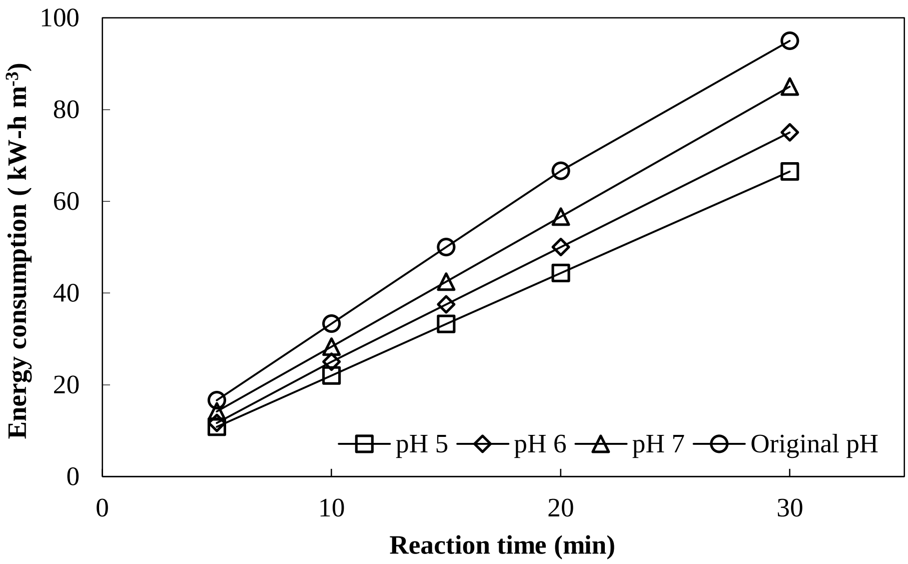

Figure 3. The effect of different initial wastewater pH values on the system's energy consumption. The current was kept constant at 10 A and the retention time at 30 min.

The energy consumption was calculated by using Eq. 2. The obtained results are shown in Fig. 3. The highest energy consumption (i.e. 95%) was achieved at the wastewater original pH of 7.8, and the lowest energy consumption (i.e. 66.5%) at the lowest pH of 5. This can be explained by the change in the electrical conductivity. The increase in the value of the electrical conductivity with the pH decrease also causes a decrease in the value of the potential difference applied to the system. The variation of potential difference values under the constant current of the system (i.e. 10 A) leads to different energy consumption values. According to Eq. 2, the decrease in potential difference (V) decreases the energy consumption if the current (I) does not change.

4. Conclusions

This study presented the results of batch experiments for the treatment of urban wastewater by means of electrocoagulation with aluminum electrodes (anode) and stainless-steel plate electrodes (cathode) placed within a labs-scale jacketed reactor. To examine the effect of initial wastewater pH as a key process parameter on the system's COD removal, four different pH values were applied: 5, 6, 7 and 7.8 (i.e. the natural initial pH of the wastewater). The current was kept constant at 10 A and the retention time at 30 minutes. Under these experimental conditions and for the original wastewater pH (i.e. 7.8%), the electrocoagulation process proved to have the potential to achieve high COD removal (approximately 73%) at very short reaction times (e.g. after only 5 min of operation). At the end of the reaction (i.e. after 30 min), the highest COD removal (≈87%) was obtained at the original wastewater pH value (i.e. 7.8). On the contrary, the lowest COD removal (≈55%) was noted for an initial wastewater pH value of 5; it was around 77% and 60% for the initial pH values of 6 and 7, respectively.

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References

[1] UNESCO: The United Nations World Water Development Report 4, Volume 1: Managing Water under Uncertainty and Risk. UNESCO, Paris (2012).

[2] Bratby, J.: Coagulants, Coagulation and Flocculation in Water and Wastewater Treatment. IWA Publishing, London (2006).

[3] Zhang, K., Farahbakhsh, K.: Removal of native coliphages and coliform bacteria from municipal wastewater by various wastewater treatment processes: implications to water reuse. Water Res. 41(12), 2816-2824 (2007).

[4] Joss, A., Baenninger, C., Foa, P., Koepke, S., Krauss, M., McArdell, C.S., Rottermann, K., Wei, Y., Zapata, A., Siegrist, H.: Water reuse: >90% water yield in MBR/RO through concentrate recycling and CO_2 addition as scaling control. Water Res. 45(18), 6141-6151 (2011).

[5] Pisarenko, A.N., Stanford, B.D., Yan, D., Gerrity, D. Snyder, S.A.: Effects of ozone and ozone/peroxide on trace organic contaminants and NDMA in drinking water and water reuse applications. Water Res. 46, 316-326 (2012).

[6] Molinos-Senante, M., Hernandez-Sancho, F., Sala-Garrido, R.: Cost-benefit analysis of water-reuse projects for environmental purposes: a case study for Spanish wastewater treatment plants. J. Environ. Manage. 92(12), 3091-3097 (2011).

[7]. Un, U.T., Onpeker, S.E., Ozel, E.: The treatment of chromium containing wastewater using electrocoagulation and the production of ceramic pigments from the resulting sludge. J. Environ. Manage. 200, 196-203 (2017).

[8]. Kobya, M., Demirbas, E., Ozyonar, F., Sirtbas, G., Gengec, E.: Treatments of alkaline non-cyanide, alkaline cyanide and acidic zinc electroplating wastewaters by electrocoagulation. Process Saf. Environ. Prot. 105, 373-385 (2017).

[9] Ochando-Pulido, J.M., Pimentel-Moral, S., Verardo, V., Martinez-Ferez, A.: A focus on advanced physico-chemical processes for olive mill wastewater treatment. Sep. Purif. Technol. 179, 161-174 (2017).

[10] Mohora, E., Rončević, S., Agbaba, J., Tubić, A., Mitić, M., Klašnja, M., Dalmacija, B.: Removal of arsenic from groundwater rich in natural organic matter (NOM) by continuous electrocoagulation/flocculation (ECF). Sep. Purif. Technol. 136, 150-156 (2014).

[11] Gatsios, E., Hahladakis, J.N., Gidarakos, E.: Optimization of electrocoagulation (EC) process for the purification of a real industrial wastewater from toxic metals. J. Environ. Manage. 154, 117-127 (2015).

[12] Taquez, H.N.I., Gilpavas, E., Blatchley, E.R., García, M.Á.G., Gómez, I.D.: Integrated electrocoagulation-electrooxidation process for the treatment of soluble coffee effluent: Optimization of COD degradation and operation time analysis. J. Environ. Manage. 200, 530-538 (2017).

[13] Hashim, K.S., Shaw, A., Khaddar, R.A., Pedrola, M.O., Phipps, D.: Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor. J. Environ. Manage. 189, 98-108 (2017).

[14] Vasudevan, S., Epron, F., Jothinathan, L., Sozhan, G.: Removal of NO_3 from Drinking Water by Electrocoagulation – An Alternate Approach. Clean: soil, air, water. 38(3), 225-229 (2010).

[15] Emamjomeh, M M., Sivakumar, M.: Fluoride removal by a continuous flow electrocoagulation reactor J. Environ. Manage. 90(2), 1204-1212 (2009).

[16] Shannag, M.A., Qodah, Z.A., Melhem, K.B., Qtaishat, M.R., Alkasrawi, M.: Heavy metal ions removal from metal plating wastewater using electrocoagulation: Kinetic study and process performance. Chem. Eng. J. 260, 749-756 (2015).

[17] Greenberg, A.E., Clesceri, L.S., Eaton, A.D.: Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington DC (1992).

[18] Yılmaz, A.E., Boncukcuoglu, R., Kocakerim, M.M.: A quantitative comparison between electrocoagulation and chemical coagulation for boron removal from boron-containing solution. J. Hazard. Mater. 149, 475-481 (2007).