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# Treatment of poultry slaughterhouse wastewaters by electrocoagulation

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**Abstract**

Treatment of poultry slaughterhouse wastewater (PSW) by electrocoagulation (EC) has been investigated batchwise in this paper. Effects of the process variables such as medium pH, electrode material, current density, and operating time are investigated on chemical oxygen demand (COD) and oil–grease removal efficiencies, electrical energy consumption, and sacrificial electrode consumption. The highest COD removal efficiency is reached with aluminum as 93%, and maximum oil–grease removal is obtained with iron electrodes as 98%. Combined use of both electrode materials in the EC unit may yield high process performances with respect to both COD and oil–grease removals. Further work needs to be carried out at pilot scale to assess the technical end economic feasibility of the process.


*Keywords:* Poultry slaughterhouse wastewater; Electrocoagulation; COD removal; Oil and grease removal; Electrolysis

## 1. Introduction

The consumption of poultry products in Turkey, which constitute a significant part of all meat consumption, has steadily been increased in, reaching about 10 kg per capita in 2003. Poultry slaughterhouses produce large amounts of wastewater containing high amounts of biodegradable organic matter, suspended and colloidal matter such as fats, proteins and cellulose [1–3]. Because of legal restrictions, rising treatment costs, and environmentally conscious consumers, the treatment of wastewaters has emerged as a major concern not only in poultry processing but also in the meat industry in general.

Aerobic and anaerobic methods have been traditionally used for the treatment of PSW. Aerobic treatment processes are limited by their high energy consumption needed for aeration and high sludge production. The anaerobic treatment of PSW is often slowed or impaired 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 [2]. Furthermore, it is also reported that anaerobic treatment is sensitive to high organic loading rates, as a serious disadvantage [3–5]. 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.

In recent years, new processes for efficient and adequate treatment of various industrial wastewaters with relatively low operating costs have been needed due to strict environmental regulations. At this point, 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 [6–8]. Moreover, during EC, the salt content of the liquid salt content does not increase appreciably, as in the case of chemical treatment [7].

EC has been proved to be an efficient method for the treatment of water and wastewater. It was tested successfully to treat textile wastewater [9–13], urban wastewater [14], landfill leachate [15], tar sand and oil shale wastewater [16], and chemical fiber plant wastewater [17]. EC has also been proposed to treat various food industry wastewaters such as, yeast wastewater [18], olive oil wastewater [19,20], restaurant wastewater [21,22], egg process wastewater [23], and oily wastewater [24–26].

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Despite to the impressive amount of scientific research on the treatment of industrial wastewaters by EC, little research has been done on the treatment of PSW by means of EC [27,28]. Thus, the purpose of the present study is to assess the performance of EC on the treatment of PSW, by exploring the effects of various process parameters such as sacrificial anode material, wastewater pH, current density, and treatment time, on the COD and oil–grease removal rates.

## 2. Experimental methods

### 2.1. Wastewater source and characteristics

The wastewater used in this work was taken from a local poultry slaughterhouse plant with 45,000 chickens per day capacity, located in the city of Gebze (Turkey), producing approximately 450 tonnes of wastewater daily. The wastewaters emerging from various operations such as chicken cutting, scalding, defeathering, eviscerating, chilling, packing, and plant cleanup are collected in an equalization tank, after being filtered using a screen filter to remove hair and solids. The raw PSW mainly consists of several organic compounds including carbohydates, starches, proteins, suspended particles, and other ingredients. Characteristics of the PSW are as follows: chemical oxygen demand (COD) 29,000–26,000 mg/L, biochemical oxygen demand (BOD) 12,000–10,000 mg/L, turbidity 600–550 NTU, oil–grease 1800–1500 mg/L, total suspended solids (TSS) 1200–840, initial pH 6.7, conductivity 1.99 mS.

### 2.2. Experimental setup

The experimental setup is shown in Fig. 1. The thermostated, plexiglass electrocoagulator with the dimensions of 65 mm × 65 mm × 110 mm, was equipped with four parallel monopolar electrodes; two anodes and two cathodes with the dimensions of 46 mm × 55 mm × 3 mm, made of aluminum (99.53%) or iron (99.50%) plates. The total effective electrode area was 80 $cm^2$ and the spacing between electrodes was 11 mm. The electrodes were connected to a dc digital power supply (Topward 6306D; 30 V, 6 A) with potentiostatic or galvanostatic operational options.

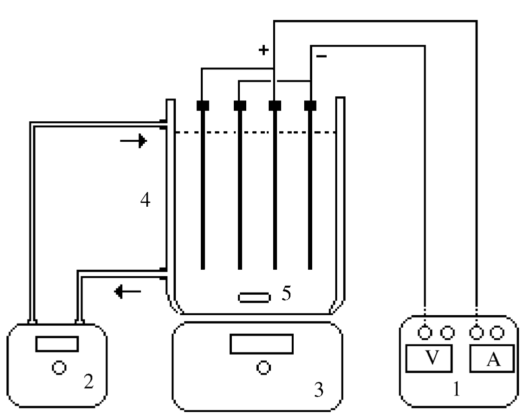


Fig. 1. Schematic diagram of experimental setup: (1) DC power supply; (2) water circulator; (3) digital magnetic stirrer; (4) electrochemical cell; (5) magnetic bar-stirrer.

Before each run, electrodes were washed with acetone to remove surface grease, then, the impurities on aluminum or iron electrode surfaces were removed by dipping for 5 min in a solution freshly prepared by mixing 100 $cm^3$ of HCl solution (35%) and 200 $cm^3$ of hexamethylenetetramine aqueous solution (2.80%), dried and weighted [10]. All runs were performed at constant temperature (25 °C), mixing speed (200 rpm), and with 250 $cm^3$ of wastewater solution. At the end of the run, the solution was filtered and then the filtrate was analysed, the electrodes were washed thoroughly with water to remove any solid residues on the surfaces, dried, and reweighted.

### 2.3. Analytical procedures

COD, BOD, oil–grease, conductivity, pH, and TSS determinations were carried out as proposed by Standard Methods [29]. COD was measured using COD reactor and direct reading spectrophotometer (DR/2000, HACH, USA). Oil–grease were determined with hexane extraction. The pH and conductivity were adjusted to a desirable value using NaOH or $H_2SO_4$, and NaCl, and measured by a AZ 8601 model pH meter, and a Lutron CD-4303 model conductivity meter, respectively.

### 2.4. A brief description of EC

Main processes which occurs during EC are as follows:

(a) Electrolytic reactions at electrode surfaces:

$$\text{Anode}: \quad M \rightarrow M^{3+}_{(aq)} + 3e^- \tag{1}$$

$$\text{Cathode}: \quad 3H_2O + 3e^- \rightarrow \frac{3}{2}H_2 + 3OH^- \tag{2}$$

where M is Fe or Al. The sacrificial electrodes may also be chemically attacked by $H^+$ ions in acidic medium, or by $OH^-$ ions in alkaline medium [21,30].

(b) Coagulation in aqueous phase:
$M^{3+}_{(aq)}$ and $OH^-$ ions generated by electrode reactions (1) and (2) react to form various hydroxo monomeric and polymeric species, depending on pH range, which transform finally into $M(OH)_3$ according to complex precipitation kinetics [31,32].

(c) Adsorption of soluble or colloidal pollutants on coagulants, and removal by sedimentation or flotation.

Freshly formed amorphous $M(OH)_3$ “sweep flocs” have large surface areas which are beneficial for a rapid adsorption of soluble organic compounds [22,24,25] and trapping of colloidal particles. These flocs polymerize further as $M_n(OH)_{3n}$ and are removed easily from aqueous medium by sedimentation and flotation [7,32].

## 3. Results and discussion

The efficiency of pollutant removal from wastewaters by EC process depends on several operating parameters: the type of

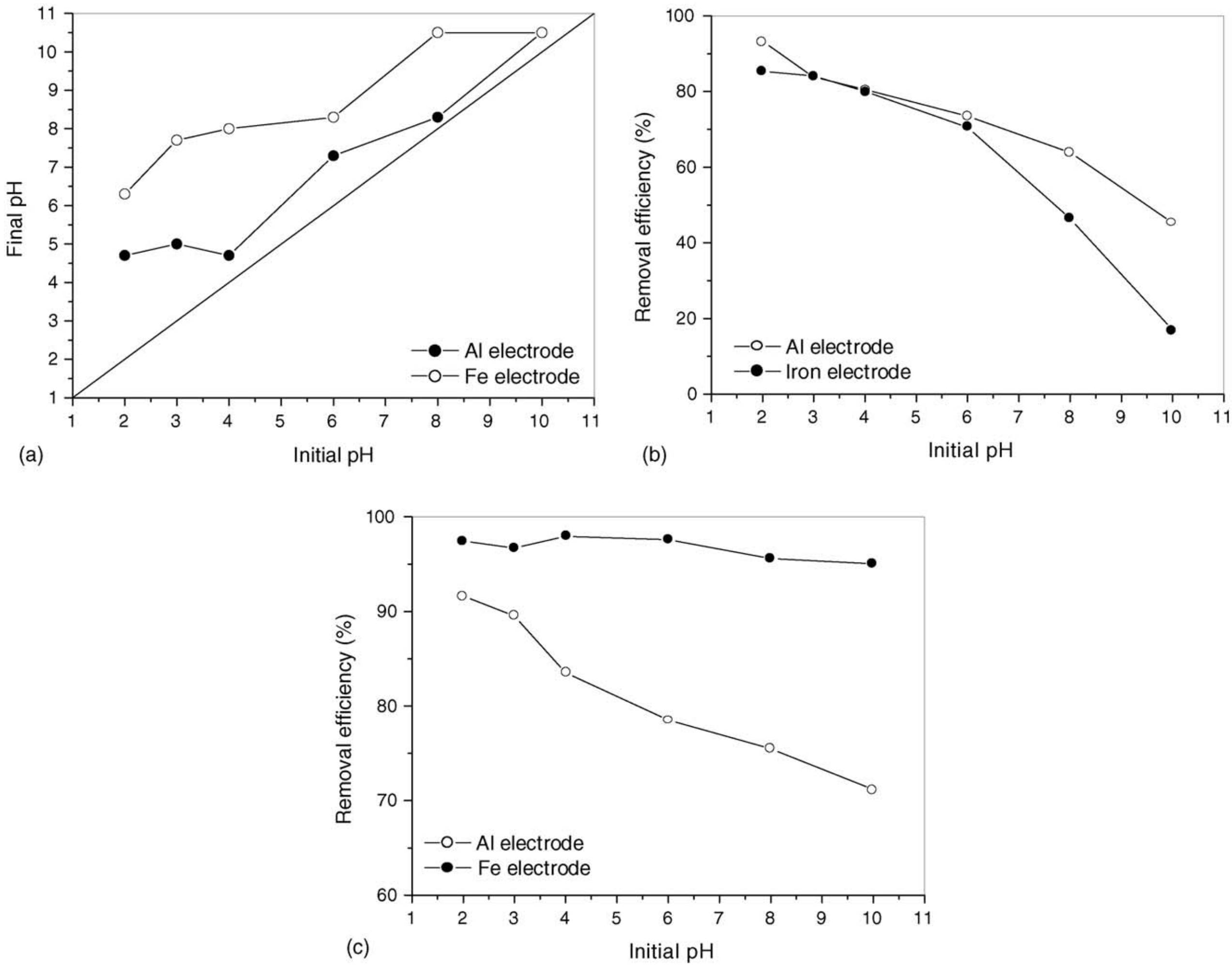


Fig. 2. (a) Effect of initial pH on final pH. (b) Effect of initial pH on COD removal. (c) Effect of initial pH on oil–grease removal.

electrode material, initial pH, current density or cell voltage, and processing time. In this study, in addition to COD removal percent, which is the primary criterium to assess the process performance, oil–grease removal percent, electrical energy and anode consumptions per cubic meter of wastewater also have been taken into consideration. The same runs are conducted with aluminum and iron electrodes separately, for comparative purpose.

### 3.1. Effect of initial pH

The effect of initial pH on the treatment of the PSW was investigated at constant current density 150 A/m$^2$ and EC time 25 min. As seen in Fig. 2(a), the two electrode materials show different relationships between initial and final pH values. In the iron case, the final pH is always greater than 6, showing two plateaus; one around pH 7.5–8, and a second around pH 10.5. In the aluminum case, the final pH exhibits a plateau in acidic pH ranges 4.5–5. These plateaus result from the buffering capacity of various processes occuring during EC [10,13,21,22].

The effect of initial pH on the COD removal efficiency is presented in Fig. 2(b), comparatively. For both electrodes, high COD removal percent may be attained in acidic mediums, the efficiency decreasing with increasing pH; at pH 2, maximum COD removal attainable is 93% with aluminum electrode, and 85% with iron electrode. Meanwhile, when original PSW (pH 6.7) is treated by EC, COD removal is 70% for aluminum, and 60% for iron electrode.

In the case of oil–grease removal, as seen in Fig. 2(c), the performance of aluminum electrode diminishes with increasing pH, from 92% at pH 2 to 64% at pH 8. In contrast to aluminum case, the iron electrode performance is not affected by initial pH between 2 and 8 and reaches high values up to 96–98%. The removal of oil–grease colloids from wastewater is accomplished according to various complicated mechanisms; in addition to adsorption on or entrapping in metal hydroxides flocs, electrophoretic destabilization by electrical field and by electrogenerated Fe or Al salts may also occur and enhance the removal efficiency of EC. This must be investigated by further researches.

The electrical energy consumption, in the aluminum case, lies between 0.5 and 1 kWh/m$^3$ for initial pH range 2–6. Above pH 8, a sharp increase in electrical energy consumption is detected. In the iron case, a minimum around 0.3 kWh/m$^3$ is observed in the energy consumption for initial pH between 3 and 4, and the energy consumption increases to high values above pH 5.

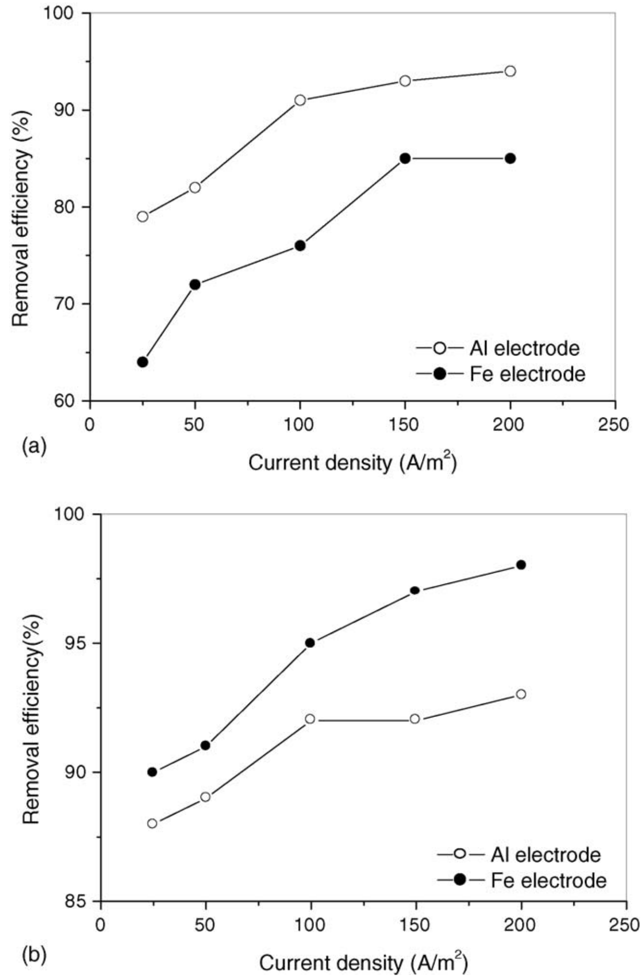


Fig. 3. (a) Effect of current density on COD removal. (b) Effect of current density on oil–grease removal.

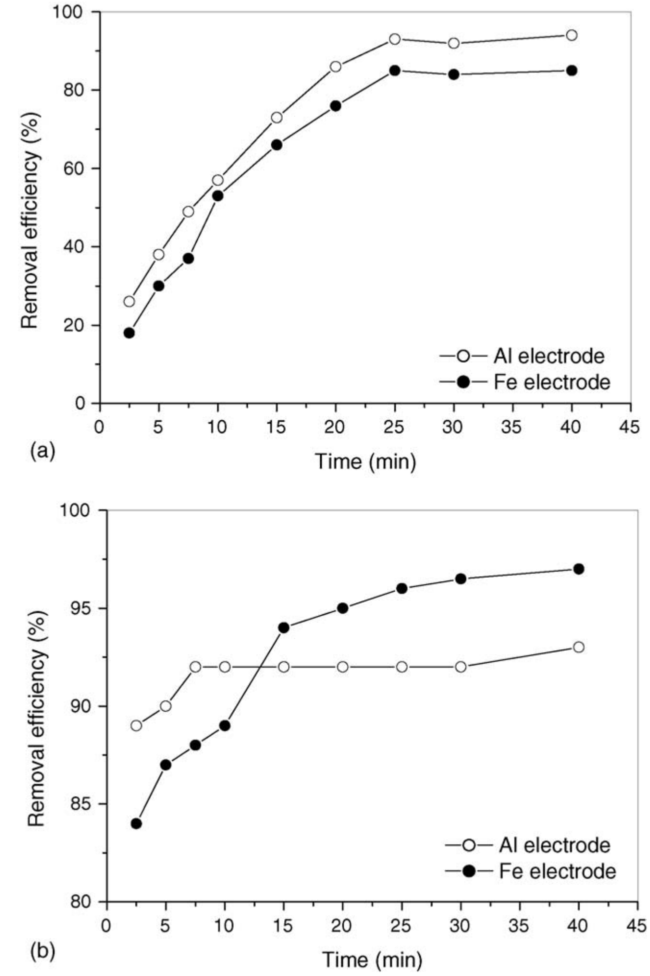


Fig. 4. (a) The effect of time on COD removal. (b) The effect of time on oil–grease removal.

Finally, total electrode consumption depends on electrode material as well as the pH of the medium. For the same electrical charge (Faraday), in acidic medium, electrodissolution of iron electrodes is higher than aluminum, while in alkaline medium, the reverse situation occurs.

### 3.2. Effect of current density

Fig. 3(a and b) represent the effects of the current density on COD and oil–grease removal efficiencies, for iron and aluminum electrode materials, with operating time 25 min and pH 2. In general, higher current density is in favour of both removal efficiencies, for both electrode materials. Above 150 A/m$^2$, COD removal efficiency reaches a limit value of 92% for aluminum, and 85% for iron. In the case of oil–grease removal, higher efficiencies are obtained; 94% with aluminum and 99% with iron. Meanwhile, higher current densities above 150 A/m$^2$ are not beneficial from economic point of view.

For both electrode materials, electrical energy consumption increases nonlinearly with increasing current density, up to 150–200 A/m$^2$, due to strong impact of the current density on the cell voltage by means of various overpotentials. The current density must be maintained below 125 A/m$^2$, to ensure low energy consumption at acceptable levels below 1 kWh/m$^3$.

On the other hands, aluminum electrode consumption is almost linear function of the current density, in accordance with Faraday electrolysis laws. In the iron case, the consumption values exhibit observable departures from Faraday's law due to the chemical attack by $H^+$.

### 3.3. Effect of time

To explore the effect of the operating time, the current density is kept constant at 150 A/m$^2$ and the pH of the wastewater is adjusted to 2. As seen in Fig. 4(a), the COD removal increases monotonically up to 93% for aluminum, and 85% for iron in 25 min and further electrogeneration of coagulant flocs has no positive effect on COD removal.

The oil–grease removal, on the other hand, reaches a constant value near 90% in 7.5 min using aluminum electrodes, whereas in the case of iron electrodes, the oil–grease removal steadily increases to 95% in 15 min (Fig. 4(b)).

Finally, electrical energy consumptions exhibit some departure from linearity, as time progresses, for both electrode materials. The electrode consumptions, on the other hands, follow a nearly linear relation with time.

## 4. Conclusions

EC is found to be an effective method for the treatment of PSW. As electrode material, aluminum electrode performs better in reducing the COD; low initial pH, such as 2–3, and current density of 150 A/m$^2$ are preferable for having a high COD removal efficiency (93%) in 25 min. Low initial pH is not very crucial due to the fact that the final pH approaches near 5–6 as a result of the buffering capacity of the various process occuring in the unit. On the other hand, iron removes oil–grease with 98% efficiency, at appropriate conditions. By means of the combined usage of iron and aluminum as anode materials at appropriate process conditions in the EC unit, high performances with respect to both COD and oil–grease removals may be accomplished. Further works conducted at pilot plant scale will reveal the economic feasibility of the treatment of PSW by EC.

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## References

[1] C.E.T. Caixeta, M.C. Cammarota, A.M.F. Xavier, laughterhouse wastewater treatment:evaluation of a new three-phase separation system in a UASB reactor, Bioresour. Technol. 81 (2002) 61–69.
[2] D. Masse, L. Masse, The effect of temperature on slaughterhouse wastewater treatment in anaerobic sequencing batch reactors, Bioresour. Technol. 76 (2001) 91–98.
[3] L.A. Nunez, B. Martinez, Anaerobic treatment of slaughterhouse wastewater in an expanded granular sludge bed (EGSB) reactor, Water Sci. Technol. 40 (1999) 99–106.
[4] R.D. Pozo, V. Diez, S. Beltran, Anaerobic pre-treatment of slaughterhouse wastewater using fixed-film reactors, Bioresour. Technol. 71 (2000) 143–149.
[5] R. Borja, C.J. Banks, Z. Wang, A. Mancha, Anaerobic digestion of slaughterhouse wastewater using a combination sludge blanked and filter arrangement in a single reactor, Bioresour. Technol. 65 (1998) 125–133.
[6] G. Chen, Electrochemical technologies in wastewater treatment, Sep. Purif. Technol. 38 (2004) 11–41.
[7] M.Y.A. Mollah, R. Schennach, J.P. Parga, D.L. Cocke, Electrocoagulation(EC)-science and applications, J. Hazard. Mater. B84 (2001) 29–41.
[8] K. Rajeshwar, J.G. Ibanez, G.M. Swain, Electrochemistry and the environment, J. Appl. Electrochem. 24 (1994) 1077–1091.
[9] M. Bayramoglu, O.T. Can, M. Kobya, M. Sozbir, Operating cost analysis of electrocoagulation of textile dye wastewater, Sep. Purif. Technol. 37 (2004) 117–125.
[10] M. Kobya, O.T. Can, M. Bayramoglu, Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes, J. Hazard. Mater. B100 (2003) 163–178.
[11] O.T. Can, M. Bayramoglu, M. Kobya, Decolorization of reactive dye solutions by electrocoagulation using aluminum electrodes, Ind. Eng. Chem. Res. 42 (2003) 3391–3396.
[12] S.H. Lin, M.L. Chen, Treatment of textile wastewater by chemical methods for reuse, Water Res. 31 (1997) 868–876.
[13] S.H. Lin, C.F. Peng, Treatment of textile wastewaters by electrochemical method, Water Res. 28 (1994) 277–876.
[14] M.F. Pouet, A. Grasmick, Urban wastewater treatment by electrocoagulation and flotation, Water Sci. Technol. 31 (1995) 275–283.
[15] C.T. Tsai, S.T. Lin, Y.C. Shue, P.L. Su, Electrolysis of soluble organic matter in leachate from landfills, Water Res. 31 (1997) 3073–3081.
[16] R.R. Renk, Electrocoagulation of tar sand and oil shale wastewater, Energy Prog. 8 (1988) 205–208.
[17] S.H. Lin, C.S. Lin, Reclamation of wastewater effluent from a chemical fiber plant, Desalination 120 (1998) 185–195.
[18] S. Khristoskova, Possibility of purification and decoloring wastewaters from the yeast industry by electrocoagulation, Nauchni Tr-Plovdski Uni. (Bul.) 22 (1984) 177–185 (Chem. Abstr. 105, 29282r, 1986).
[19] N. Adhoum, L. Monser, Decolorization and removal of phenolic compounds from olive mill wastewater by electrocoagulation, Chem. Eng. Process. 43 (2004) 1281–1287.
[20] H. Inan, A. Dimoglu, H. Simsek, M. Karpuzcu, Olive oil mill wastewater treatment by means of electrocoagulation, Sep. Purif. Technol. 36 (2004) 23–31.
[21] X. Chen, G. Chen, P.L. Yue, Separation of pollutants from restaurant wastewater by electrocoagulation, Sep. Purif. Technol. 19 (2000) 65–76.
[22] X. Chen, G. Chen, P.L. Yue, Electrocoagulation and electroflotation of restaurant wastewater, J. Environ. Eng. 126 (2000) 858–863.
[23] L.J. Xu, B.W. Sheldon, D.K. Larick, R.E. Carawan, Recovery and utilization of useful by-products from egg processing wastewater by electrocoagulation, Poultry Sci. 81 (2002) 785–792.
[24] L.S. Calvo, J.P. Leclerc, G. Tanguy, M.C. Cames, G. Paternotte, G. Valentin, A. Rostan, F. Lapicque, An electrocoagulation unit for the purification of soluble oil wastes of high COD, Environ. Prog. 22 (2003) 57–65.
[25] X. Chen, G. Chen, P.L. Yue, Novel electrode system for electroflotation of wastewater, Environ. Sci. Technol. 36 (2002) 778–783.
[26] J.G. Ibanez, M. Takimoto, R. Vasquez, K. Rajeshwar, S. Basak, Laboratory experiments on electrochemical remediation of the environment: electrocoagulation of oily wastewater, J. Chem. Educ. 72 (1995) 1050–1052.
[27] E.C. Beck, A.P. Giannini, E.R. Ramirez, Electrocoagulation clarifies food wastewater, Food Technol. 22 (1974) 18–19.
[28] E.R. Ramirez, D.L. Johnson, O.A. Clemens, Direct comparison in physicochemical treatment of packinghouse wastewater between dissolved air and electroflotation, Proc. 31st Purdue Ind. Waste Conf., Ann Arbor Sci., Ann Arbor, Michigan, 1976, pp. 563–573.
[29] American Public Health Association (APHA), Standard Methods for Examination of Water and Wastewater, 17th ed., Washington, DC, 1992.
[30] T. Picard, G. Cathalifaund-Feuillade, M. Mazet, C. Vandensteendam, Cathodic dissolution in the electrocoagulation process using aluminum electrodes, J. Environ. Monit. 2 (2000) 77–80.
[31] O.Y. Pykhteev, A.A. Ofimov, L.N. Moskvin, Hydrolysis of iron(III) aqua complexes, Russ. J. Appl. Chem. 72 (1999) 9–20.
[32] M. Rebhun, M. Lurie, Control of organic matter by coagulation and floc separation, Water Sci. Technol. 27 (1993) 1–20.