Electrocoagulation technique in enhancing COD and suspended solids removal to improve wastewater quality

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Abstract This paper presents a preliminary study for the removal of COD and suspended solids in wastewater treatment by combining magnetic field and electrocoagulation (EC) technology. The experiments were carried out using batch apparatus and setup in the static method. Batch experiments with two monopolar iron (Fe) plate anodes and cathodes were employed as electrodes. Wastewater samples were prepared from milk powder with an initial COD of $1,140\,mgL^{-1}$ and suspended solids of $1,400\,mgL^{-1}$ and acidic conditions were employed (pH $\sim$ 3). DC current was varied from $0.5-0.8$ A and operating times were between 30 and 50 min. The results show that the effluent wastewater was very clear (turbidity ~ 9 NTU) and its quality exceeded the direct discharge standard. The suspended solids and COD removal efficiencies were as high as 30.6 and 75.5%, respectively. In addition, the experimental results also show that the electrocoagulation could neutralise the pH of wastewater.

Keywords COD removal; electrocoagulation; iron electrode; suspended solids

Introduction

Floc size and density significantly influence the performance of solid/liquid separation processes. Large and dense flocs may be preferable since they have high sedimentation velocities and are more easily dewatered. Chemical dosing with metal ions (iron or aluminium) is often used in primary treatments to remove colloids from wastewater, but new technologies such as electrocoagulation are suspectible to produce flocs of higher size and density (Larue and Vorobiev, 2003).

Electrocoagulation (EC) is suspectible to produce flocs of higher size and density. EC is considered as a low sludge producing technology. The flocs formed by EC are relatively large, contain less bound water, are more stable and, therefore, amenable to filtration. Chemical aids are not required in EC, which can be easily integrated with conventional waste control system (Chen *et al.*, 2000; Mollah *et al.*, 2001, 2004).

Electrocoagulation (EC) was used for wastewater treatment in the previous work by numerous authors and several differences were found in the chemical coagulation processes. A literature survey indicates that EC is an efficient treatment process for different wastes, e.g. soluble oils, liquid from the food, textile industries or cellulose and effluents from the paper industry (Holt *et al.*, 2002; Calvo *et al.*, 2003; Larue *et al.*, 2003; Kumar *et al.*, 2004; Carmona *et al.*, 2006). EC is an effective process for the desta-bilisation of finely dispersed particles by removing hydrocarbons, greases, suspended solids and heavy metals from different types of wastewater (Kumar *et al.*, 2004; Carmona *et al.*, 2006). According to Can *et al.*, (2006), in recent years, EC has been proposed as an effective method to treat various wastewaters such as landfill leachate, restaurant

wastewater, saline wastewater, tar sand and oil shale wastewater, urban wastewater, laundry wastewater, nitrate and arsenic bearing wastewater and chemical mechanical polishing wastewater.

Pletcher and Walsh (1990, in Lin *et al.*, 1998) explained that the mechanism of the electrochemical process in aqueous systems is quite complex. It is generally believed that there are three possible mechanisms involved in the process: electro-coagulation, electro-flotation and electro-oxidation. According to Can *et al.*, (2006), three main processes occur during EC: (i) electrolytic reaction at electrode surfaces; (ii) formation of coagulants in the aqueous phase; (iii) adsorption of soluble or colloidal pollutants on coagulants and removal by sedimentation or flotation.

Aluminium or iron are usually used as electrodes and their cations are generated by dissolution of sacrificial anodes upon the application of a direct current (Carmona *et al.*, 2006). Kobya *et al.*, (2003) investigated EC technologies for the treatment of textile wastewaters using iron and aluminium electrode materials. The result shows that from COD removal efficiency and energy consumption points of view, iron is superior to aluminium as a sacrificial electrode material.

In EC with electrical current flowing between two electrodes, coagulant is generated *in situ* by electrolytic oxidation of the anode material. With an iron anode, $Fe(OH)_2$ or $Fe(OH)_3$ is formed at the anode. According to Larue *et al.*, (2003), the generation of iron hydroxides (Fe(OH)n) is followed by an electrophoretic concentration of colloids (usually negatively charged) in the region close to the anode. Particles interact with the iron hydroxides and are removed either by surface complexation or electrostatic attraction (Mollah *et al.*, 2001; Daneshvar *et al.*, 2003, 2004, 2006).

Experimental procedures

In this study, the effect of electrocoagulation (EC) process on COD and suspended solids (SS) removal were examined using three variables: direct current (i); treatment time (t_1); and settling time (t_2). This research focused on the capability of the EC technology to remove and settle suspended solids and improve wastewater quality.

The synthetic wastewater was made of milk powder and treated using HCl 1 M as pH adjusment and electrolyte. The composition of artificial wastewater is shown in Table 1. The concentration of HCl was 5 mL/L (0.5%) and the maximum input current was 1.0 A at voltage 30 V. The current density was adjusted to a desired value and the coagulation was started.

The experiment was setup in the static method where the EC and artificial wastewater batch test are performed in a cylindrical glass cell (volume 2,000 mL) and stirred at the constant speed (Figure 1). Stirring was provided by a plate impeller from plastic material ($\varnothing$ 3 cm) at a rotating velocity of 100 rpm (Heidolph RZR-2101 Electronic).

For EC tests, the monopolar iron (Fe) plate electrodes (130 × 50 × 4 mm) were used and the distance between each pair of electrodes was 50 mm. Electrodes were placed in 2 L of wastewater and connected to terminals of a DC Power Supply (Lodestar 8107; 30V/10A) with potentiostatic or galvanostatic operational options. The DC current was

Table 1 Characteristics of wastewater

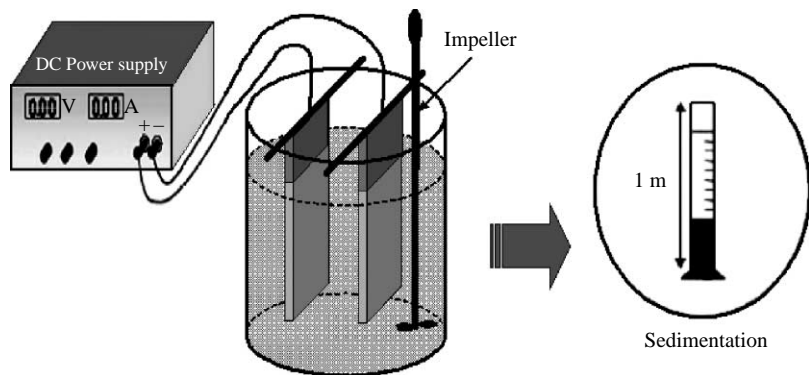| Parameter	Value
Chemical oxygen demand COD (mg/L)	1,140
Total suspended solids TSS (mg/L)	1,400
Turbidity (NTU)	491
Initial pH	7.45
pH after adjusted by HCl	2.91

Figure 1 Static system apparatus

kept constant at 0.50A, 0.65A and 0.80A. Bubbles generated from water electrolysis in EC could float flocs to the top of the suspension. After EC process, fluid wastewater was degassed at a low stirring speed with an impeller velocity of 30 rpm.

After EC treatment the fluid wastewater was placed in graduated sedimentation columns of 5 cm internal diameter and 1 m height (Figure 1). During the 30 min settling time interval the effects of relevant wastewater characteristics, such as pH, turbidity, COD and SS, removal efficiencies were examined.

The pH of the solutions was measured by a pH meter (Thermo Orion Model 420 A +). Thermal analysis was performed and equipped using a Hanna Instrument Checktemp HI-98501. The turbidity removal was measured from wastewater samples by Hach DR / 4000 (Hach Method 10047). COD measurments were determined according to the *Standard Methods for Examination of Water and Wastewater* (APHA Method 5220 C). An Hach COD reactor was used for digestion of the sample in COD vials. COD was spectrophotometrically determined by using an Hach DR/4000 spectrophotometer.

To determine the total suspended solids (TSS), the wastewater samples were filtered through a standard GF/F glass fibre filter. The residual retained on the filter was dried in an oven at $103-105°C$ to a constant weight. The increase in weight of the filter represents the total suspended solids (APHA Method 2540 D).

The calculation of turbidity and suspended solid removal efficiencies after electrocoagulation treatment were performed using this equation (Daneshvar *et al.*, 2006):

$$CR(\%) = \frac{C_0 - C}{C_0} \times 100 \tag{1}$$

where C_0 and C are concentrations of wastewater before and after electrocoagulation in NTU or mg/L, respectively.

Results and discussion

Effect of treatment time

It can be seen in Figure 2 that pH will increase as the time of the EC process is increased. This could be because the OH^- ion will accumulate in aqueous solution during the process. The increasing of pH at acidic conditions gives an attribute to hydrogen evolution at the cathodes.

In the previous work, Daneshvar *et al.*, (2006) and Kobya *et al.*, (2006) explained that pH was an important factor that could influence the treatment performance of the electocoagulation process. Kobya *et al.*, (2003) and Chen *et al.*, (2000) also determined that the pH of the medium usually changes during the process.
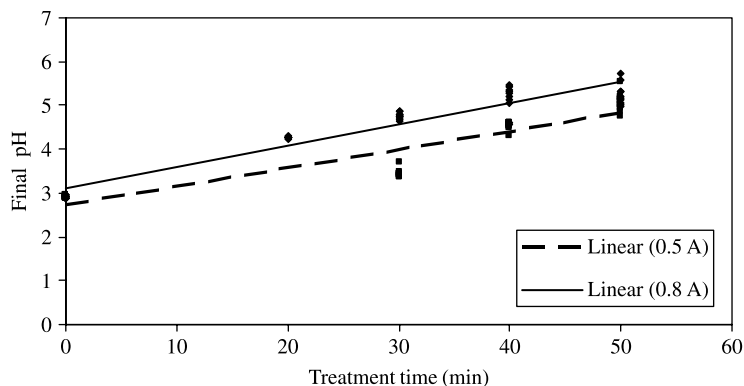
Figure 2 Effect of EC process on values change of pH

The effluent treated with iron electrode as anode appeared greenish first and then turned yellow and turbid. This green and yellow colour must have resulted from Fe^{2+} and Fe^{3+} ions generated during the EC process. Fe^{2+} is the common ion generated *in situ* of electrolysis of iron electrode. It has relatively high solubility at acidic or neutral conditions and can be oxidised easily into Fe^{3+} by dissolved oxygen in water.

Figure 3 illustrates the removal of COD and turbidity as a function of treatment time. It is clearly seen from Figure 3 that the treatment time has a significant effect on the pollutant removal. When the treatment time changed from 10 to 50 min, the removal of COD from 968 to 267 mg/L and turbidity from 486 to 10 NTU was obtained. In this process, electrocoagulation involves two stages which are destabilisation and aggregation. The first stage is usually short, whereas the second stage is relatively long.

From Figure 3 it can be seen that metal ions as a destabilisation agent are produced at the anode through electrochemical reactions. When the treatment time was quick, so the charge loading was low. In such conditions, the metal ion (Fe^{3+}) dosage was not sufficient to destabilise all colloidal and finely suspended particles. Thus the COD and turbidity removal efficiencies were not high.

On the other hand, to explore the effect of the treatment time on the temperature, the initial temperature of solution was kept constant at 26 °C. Figure 4 explains the relationship between operating time and temperature. As shown in Figure 4, the temperature increases when the operating time of the EC is increased. This occurred because the
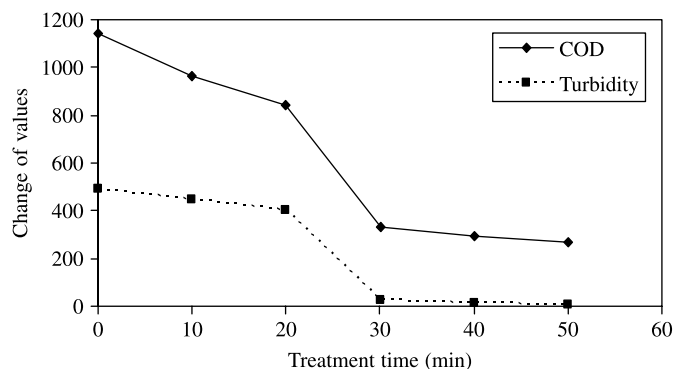
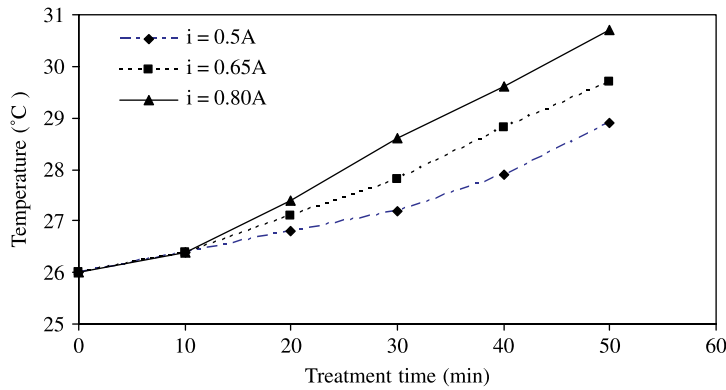**Figure 3** Effect of treatment time on the removal of COD and Turbidity (I = 0.8 A)

Figure 4 Effect of treatment time on temperature

EC treatment brings about the heating of suspension by Joule's effect, Q (Larue *et al.*, 2003). The relationship between temperature and Joule's effect is expressed by the following formula:

$$\Delta T = \frac{Q}{C_p} \tag{2}$$

where C_p is the calorific capacity of the suspension supposed to be close to the calorific capacity of water.

Effect of settling time

From the batch studies involving various settling time presented for the TSS removal experiment (Figure. 5), the best efficiency started after 120 min of sedimentation. As seen in Figure 5, suspended particle removal increases as the settling time is increased. With additional treatment time of between 30 and 50 min, TSS removal is increased from 8.5 to 25.6% at 120 min of settling time, whereas at 240 min of settling time, TSS removal is increased between 11.4 and 30.6%.

As depicted in Figure 6, the COD removal efficiency is increased to a value of more than 65%. At 240 min of settling time, COD removal is increased to 65.2% for 30 min treatment time, while 40 min is 70.7% and 50 min is 75.5%.
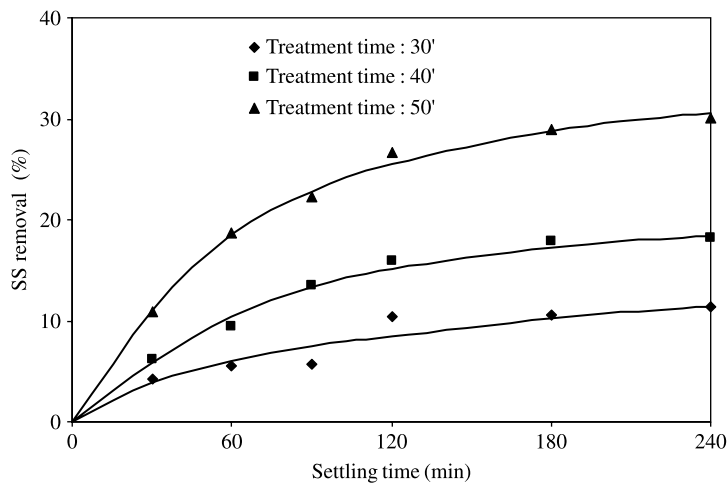

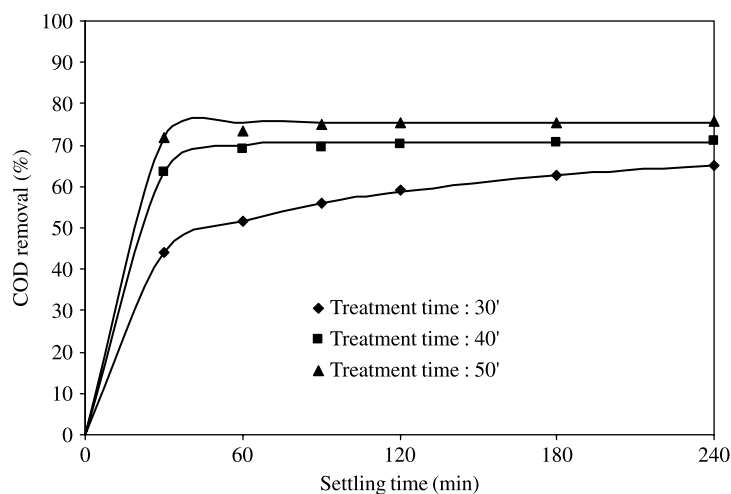**Figure 5** TSS removal efficiencies as a function of settling time ($I = 0.8\,\text{A}$; $t = 30 - 50\,\text{min}$)

Figure 6 COD removal efficiencies as a function of settling time ($I = 0.8\,A$; $t = 30-50\,min$)

The behaviour of these processes (Figures 3, 5 and 6) explains that the EC technology can enhance the settling velocity of suspended particles and increase COD removal.

Conclusion

Suspended particles removal from wastewater using the EC technique was measured in the batch studies of a single stirred apparatus. The monopolar iron (Fe) plate electrodes were used in this work and were set at a distance of 50 mm in the cylindrical glass cell (volume 2,000 mL).

The results show that the suspended solids and COD removal efficiencies are as high as 30.6 and 75.5% at 240 min of settling time, respectively. In general, the results obtained from the curves of treatment time and settling time explain that the EC technology could enhance the settling velocity of suspended particles and increase the COD removal. It means that the EC technology can separate the suspended particles from wastewater and improve its quality.

Acknowledgements

References

Calvo, L.S., Leclerc, J.P., Tnguy, G., Cames, M.C., Paternotte, G., Valentin, G., Rostan, A. and Lapicque, F. (2003). An electrocoagulation unit for the purification of soluble oil wastes of high COD. *Environ. Prog.*, **22**(1), 57–65.

Can, O.T., Kobya, M., Demirbas, E. and Bayramoglu, M. (2006). Treatment of the textile wastewater by combined electrocoagulation. *Chemosphere*, **62**, 181–187.

Carmona, M., Khemis, M., Leclerc, J.P. and Lapicque, F. (2006). A simple model to predict the removal of oil suspensions from water using the electrocoagulation technique. *Chem. Eng. Sci.*, **61**, 1237–1246.

Chen, X., Chen, G. and Yue, P.L. (2000). Separation of pollutants from restaurant wastewater by electrocoagulation. *Sep. Purif. Tech.*, **19**, 65–76.

Daneshvar, N., Sorkhabi, H.A. and Tizpar, A. (2003). Decolorization of orange II by electrocoagulation method. *Sep. Purif. Tech.*, **31**, 153–162.

Daneshvar, N., Sorkhabi, H.A. and Kasiri, M.B. (2004). Decolorization of dye solution containing acid red 14 by electrocoagulation with a comparative investigation of different electrode connections. *J. Hazard. Mat.*, **B112**, 55–62.

Daneshvar, N., Oladegaragoze, A. and Djafarzadeh, N. (2006). Decolorization of basic dye solutions by electrocoagulation: an investigation of the effect of operational parameters. *J. Hazard. Mat.*, **B129**, 116–122.

Holt, P.K., Barton, G.W., Wark, M. and Mitchell, C.A. (2002). A quantitative comparison between chemical dosing and electrocoagulation. *Colloids Surfaces A: Physicochem. Eng. Asp.*, **211**, 233–248.

Kobya, M., Can, O.T. and Bayramoglu, M. (2003). Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes. *J. Hazard. Mat.*, **B100**, 163–178.

Kobya, M., Hiz, H., Senturk, E., Aydiner, C. and Demirbas, E. (2006). Treatment of potato chips manufacturing wastewater by electrocoagulation. *Desalination*, **190**, 201–211.

Kumar, P.R., Chaudhar, S., Khilar, K. and Mahajan, C. (2004). Removal of arsenic from water by electrocoagulation. *Chemosphere*, **55**, 1245–1252.

Larue, O. and Vorobiev, E. (2003). Floc size estimation in iron induced electrocoagulation and coagulation using sedimentation data. *Int. J. Mineral Proc.*, **71**, 115.

Larue, O., Vorobiev, E., Vu, C. and Durand, B. (2003). Electrocoagulation and coagulation by iron of latex particles in aqueous suspensions. *Sep. Purif. Tech.*, **31**, 177–192.

Lin, S.H., Shyu, C.T. and Sun, M.C. (1998). Saline wastewater treatment by electrochemical method. *Water Res.*, **32**(4), 1059–1066.

Mollah, M.Y.A., Schennach, R., Parga, J.R. and Cocke, D.L. (2001). Electrocoagulation (EC) – science and applications. *J. Hazard. Mat.*, **B84**, 29–41.

Mollah, M.Y.A., Morkovsky, P., Gomes, J.A.G., Kesmez, M., Parga, J. and Cocke, D.L. (2004). Fundamentals, present and future perspectives of electrocoagulation. *J. Hazard. Mat.*, **B114**, 199–210.