ENHANCING SUSPENDED SOLIDS REMOVAL FROM WASTEWATER USING Fe ELECTRODES

Fadil Othman[1,*], Johan Sohaili[1], Moh Faiqun Ni'am[2], Zulfa Fauzia[3]

[1] *Environmental Engineering Department., Faculty of Engineering, Universiti Teknologi Malaysia, Johor, Malaysia*
[2] *Civil Engineering Department, Universitas Islam Sultan Agung, Semarang, Indonesia*
[3] *Civil Engineering Department, Universitas Indonesia, Jakarta, Indonesia*

Corresponding Author: dfadilos@utm.my

Abstract: This paper investigates the effect of electrocoagulation (EC) process on the removal of suspended solids (SS) from wastewater. In a batch electrochemical cell experimental set up, two monopolar iron (Fe) plate were used as electrodes (anodes and cathodes). Synthetic wastewater, made of milk powder with concentration of 700 mg/L, was treated using 1M HCl for pH adjustment before it was used as electrolyte. Preliminary results show that the EC process is able to enhance the removal of suspended solid, turbidity and carbon oxygen demand in wastewater. The removal rates of those elements were increase with treatment time.

Keywords: *Wastewater; Electrocoagulation; Iron electrode; Suspended solids.*

Abstrak: Tujuan kertas kerja ini adalah untuk menyelidiki kesan proses elektrokoagulasi (EC) bagi mengurangkan pepejal terampai dari air sisa. Di dalam ujikaji berskala makmal menggunakan sel elektrokimia jujukan, dua keping plat besi (Fe) monopolar telah digunakan sebagai elektrod (anod dan katod). Susu tepung dengan kepekatan 700 mg/L, telah diolah menggunakan HCl 1 M sebagai pengawal pH dan elektrolit. Keputusan awal mendapati bahawa teknologi EC mampu meningkatkan penyingkiran pepejal terampai, kekeruhan dan COD. Kadar penyingkiran ini meningkat seiring dengan tempoh pengolahan dan tempoh pemendapan.

Katakunci: *Air sisa; Elektrokoagulasi; Elektrod besi; Pepejal terampai.*

1.0   1ntroduction

A wide range of wastewater treatment techniques are available which include biological and physico-chemical processes that generally require chemical additions. A host of promising techniques based on electrochemical technology have been developed and improved (Mollah et al., 2001; Mollah et al., 2004; Chen et al., 2004; Holt et al., 2005). These include electrocoagulation (EC), electroflotation (EF), electrodeposition (ED) and electrooxidation (EO) (Chen, 2004). Although it is commercially viable, EC received very little scientific attention (Mollah et al., 2001).

Treatment of wastewater using EC technique has been practiced through out the 20th century but with limited success (Daneshvar et al., 2004). The use of electricity to treat water was first proposed in UK in 1889, and the application of electrolysis in mineral beneficiation was patented by Elmore in 1904 (Chen, 2004). The principle of EC as applied for the treatment of bilge water from ships was first patented in 1906 by A. E. Dietrich (Pathak, 2003).

Electrocoagulation is an efficient treatment process for various type of wastes such as soluble oils, liquid from food, textile industries, cellulose and effluents from paper industry (Calvo et al., 2003). According to Can et al. (2006), EC has been proposed in recent years as an effective method to treat various wastewaters such as landfill leachate, effluent from restaurant, saline wastewater, tar sand and oil shale wastewater, urban wastewater, laundry wastewater, nitrate and arsenic bearing wastewater and chemical-mechanical polishing wastewater.

Electrocoagulation technology for wastewater treatment has gone through considerable technical improvements. It is a complicated electrochemical process involving many chemical and physical phenomena that employs consumable electrodes to supply ions into the wastewater stream (Mollah et al., 2004). The underlying principle of EC (Figure 1) is the generation of cations by the dissolution of sacrificial anodes that induce flocculation of the dispersed pollutants contained by the zeta potential reduction system (Calvo et al., 2003; Mollah et al., 2004).
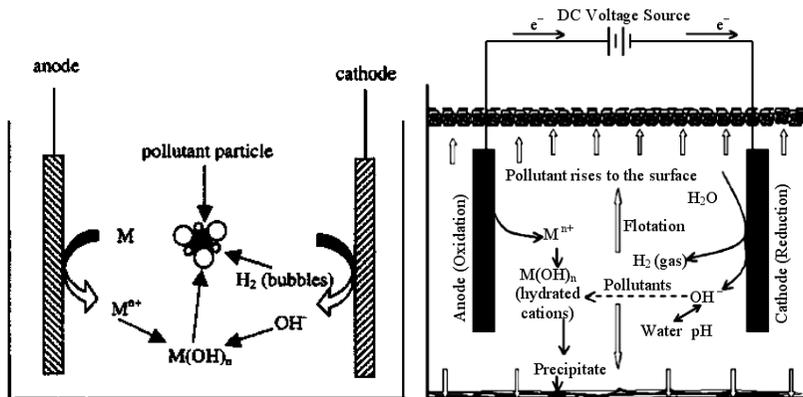

Figure 1: Principle of electrocoagulation (Calvo et al., 2003; Mollah et al., 2004)

The mechanism of the Electrochemical process in aqueous systems is quite complex (Lin et al., 1998). There are three possible mechanisms involved in the process, i.e. electro-coagulation, electro-flotation and electro-oxidation.

In EC, with electrical current flowing between two electrodes, the coagulant is generated in situ by electrolytic oxidation of the anode material. By using an iron anode, Mollah et al., (2001) observed that formation of $Fe(OH)_n$ with n = 2 or 3 is formed at the anode. Simplified oxidation and reduction mechanisms at the anode and cathode of the iron electrodes are represented as follows (Mollah et al., 2001; Daneshvar et al., 2003; Larue et al., 2003; Daneshvar et al., 2004; Daneshvar et al., 2006);

(a) Mechanism 1 :

Anode : $Fe (s) \rightarrow Fe^{2+} (aq) + 2 e^-$

$Fe^{2+} (aq) + 2 OH^- (aq) \rightarrow Fe(OH)_2 (s)$

Cathode : $2 H_2O (l) + 2 e^- \rightarrow H_2 (g) + 2 OH^- (aq)$

Overall : $Fe (s) + 2 H_2O (l) \rightarrow Fe(OH)_2 (s) + H_2 (g)$

(b) Mechanism 2 :

Anode : $4 Fe (s) \rightarrow 4 Fe^{2+} (aq) + 8 e^-$

$4 Fe^{2+} (aq) + 10 H_2O (l) + O_2 (g) \rightarrow 4 Fe(OH)_3 (s) + 8 H^+ (aq)$

Cathode : $8 H^+ (aq) + 8 e^- \rightarrow 4 H_2 (g)$

Overall : $4 Fe (s) + 10 H_2O (l) + O_2 (g) \rightarrow 4 Fe(OH)_3 (s) + 4 H_2 (g)$
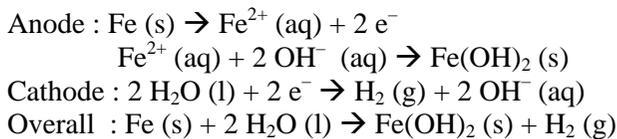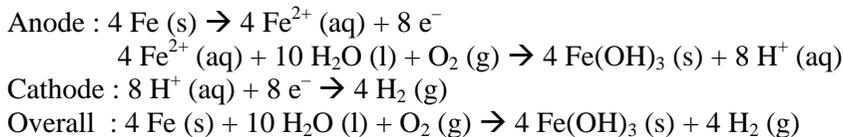
According to Larue et al. (2003), the generation of iron hydroxides $(Fe(OH)n)$ is followed by an electrophoretic concentration of colloids (usually negatively-charged) in the region close to the anode. Particles interact with the iron hydroxides are removed either by surface complexation or electrostatic attraction (Mollah et al., 2001; Daneshvar et al., 2003, 2004, 2006).

In this study, the effect of the EC process on suspended solids (SS) removal were examined using three variables: DC (i), EC time (t_1), and settling time (t_2). This research focused on the capability of the EC to remove and settle suspended solids through static processing methods.

2.0 Materials and Methods

2.1 Experimental

The present experiments were setup according to static methods. EC and fluid wastewater batch tests were performed in a cylindrical glass cell of 2000 mL capacity, stirred at a constant speed using a plate impeller from plastic material of 3cm diameters at a rotating velocity of 100 rpm (Figure 2).
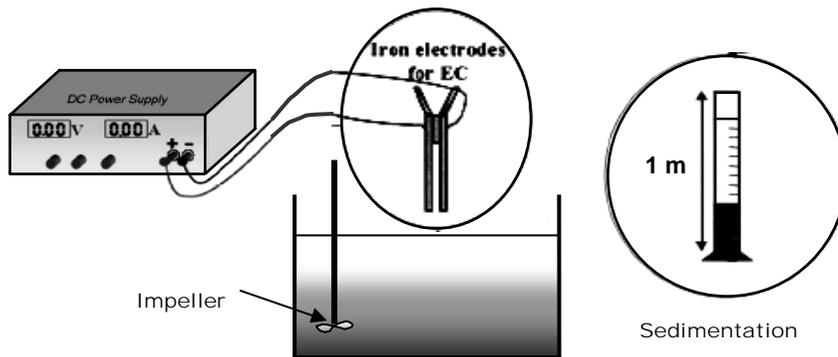
Figure 2: Static system setup of electrocoagulation process

Table 1: Characteristics of the artificial wastewater used in this experiment

Parameter	Value
Chemical oxygen demand COD (mg/L)	1140
Total suspended solids TSS (mg/L)	1400
Turbidity (NTU)	491
Initial pH	7.45
pH after adjusted by HCl	2.91

An artificial wastewater prepared from milk powder with concentration of 700 mg/L was treated using 1M HCl for pH adjusment before it was used as electrolyte. The chemical characteristics of the artificial wastewater are given in Table 1. The concentration of HCl in this fluid was 5 mL/L (0.5 %) and the maximum current obtained was 1.0 A at voltage 30 V. The current was adjusted between 0.2A and 0.8A before the coagulation process was started.

In the EC treatment configuration, the monopolar iron (Fe) plate electrodes (130 x 50 x 4 mm) were used and the spacing between each pair of electrodes was 50 mm. Electrodes were placed in the 2L artificial wastewater and connected to terminals of a DC Power Supply (30 V; 10 A) with potensiostatic or galvanostatic operational options. The bubbles generated from water electrolysis in EC would be floated and it would cover the surface of the suspension. After the EC process, the wastewater was degassed by a low speed stirrer with an impeller velocity of 30 rpm.

2.2   Settling Tests

The fluid wastewater produced by the EC treatment was transferred into a graduated sedimentation column (Figure 2). The pH, turbidity, COD and SS removal efficiencies were examined every 30 minutes.

2.3   Analytical Procedures

The pH and temperature of the solutions was measured using pH meter (Thermo Orion Model 420 A+) and HANNA Instrument Checktemp HI-98501, respectively. The turbidity was measured by HACH DR/4000 (HACH Method 10047). COD was determined according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1992) using UV-Vis HACH DR/4000 spectrophotometer (HACH Method 8000).

   To determine SS, the wastewater samples were filtered through a standard GF/F glass fibre filter. The residual retained on the filter was then oven dried at 105^0C to a constant weight (APHA Method 2540 D).

   Turbidity and SS removal efficiencies after electrocoagulation treatment were assessed using the following formula (Daneshvar et al., 2006):

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

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

3.0   Results and Discussion

3.1   pH during EC process

The pH of the medium increased during the EC process (Figure 3). A similar trend was also observed by other investigators (Chen et al., 2000; Kobya et al., 2003).   It has been recognized that the initial pH of effluent is an important parameter influencing the performance of the EC process (Daneshvar et al., 2006). The initial pH of the wastewater can be adjusted by adding HCl. The initial pH of 2.79 was used in this particular study.

$$R^2 = 0.9391$$
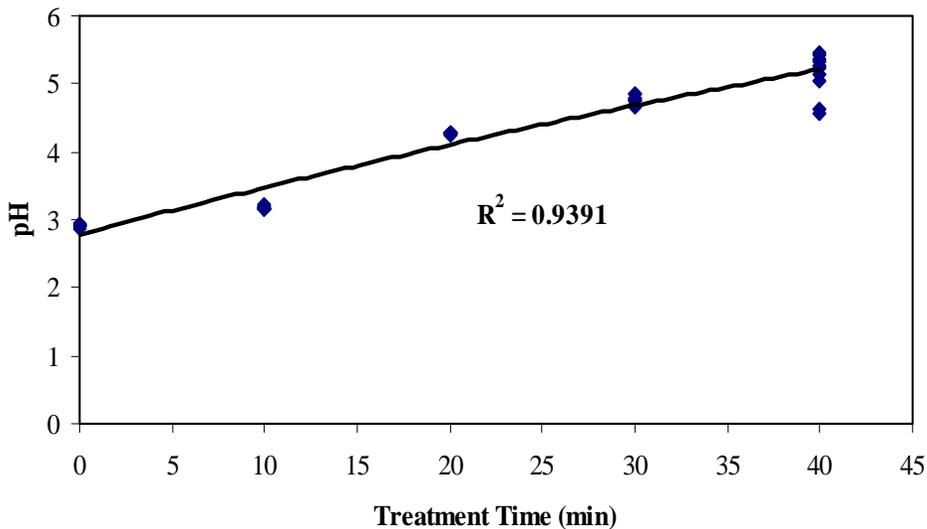
Figure 3: pH change during the EC process (the value of current : 0.8 A)

3.2   *Suspended Solids Removal*

The effect of treatment time on the settling velocity of SS was investigated by applying different DC's, i.e. 0.2 A, 0.5 A and 0.8 A. The effect of treatment time and SS removal under the DC of 0.8 A can be visualized in Figure 4a. The rate of change in concentration (C/Co) indirectly indicates the removal performance of SS. As seen, the SS removal increases with the treatment time.

The most efficient settling time was observed to occur between 0 and 240 minutes after the treatment started. At 240 minutes settling time, the SS removals were 11.43% and 18.14% for the 30 and 40 minutes treatment times, respectively. The highest removal of SS (30.14%) was observed to occur at 50 minutes treatment time.

The reason for such behavior could be due to the fact that the EC treatment may induce the settling velocity of the suspended particles in which more suspended particles agglomerate cloaked together. The exposure of wastewater to EC treatment would contribute to a greater ionic charge so that more particles would collide among themselves. This would eventually help in enhancing particles attraction and agglomeration.

3.3   *Turbidity Removal*

The effluent treated with iron electrode as anode, initially turned greenish before it turned yellow and turbid. These green and yellow colours must have been resulted from

(a)

(b)
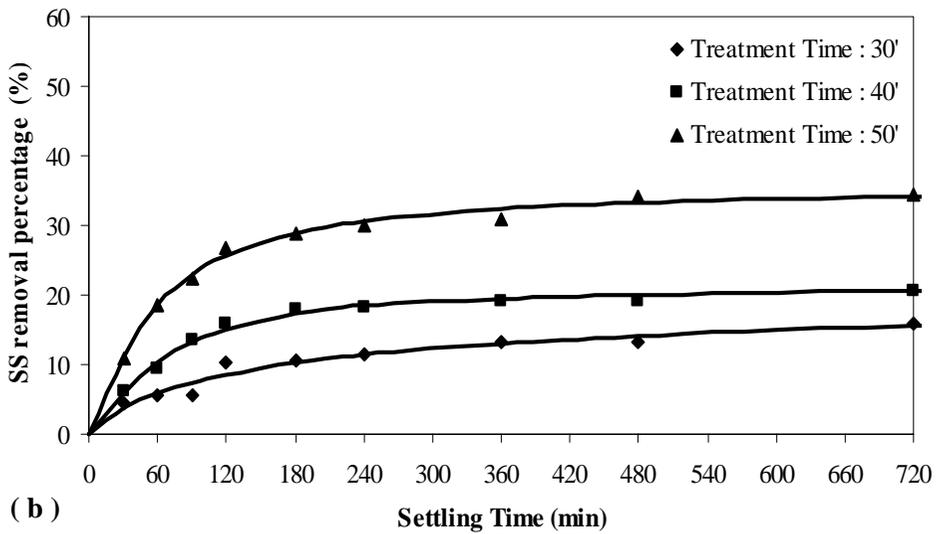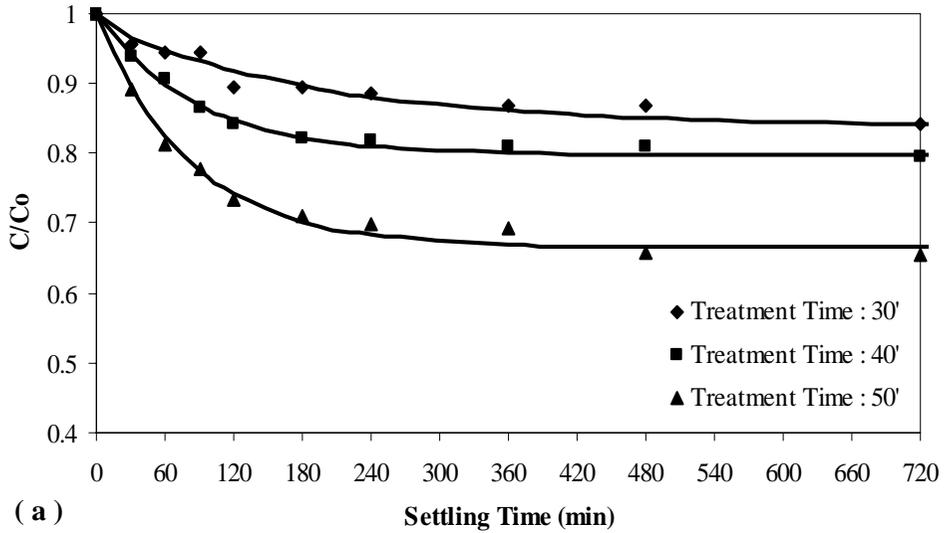
Figure 4: Effect of EC time on SS removal at DC of 0.8 A

Fe^{2+} and Fe^{3+} ions generated during the EC process. Fe^{2+} is the common ion generated in the solution due to electrolysis of iron electrode. It has relatively high solubility in acidic or neutral conditions and can be oxidised easily into Fe^{3+} by dissolved oxygen in water. After the initial increase in turbidity, the EC process reduced the turbidity from

491 NTU to 13 NTU. The turbidity removal efficiency as a function of settling time is demonstrated in Figure 5. It can be observed that the EC process enhanced the turbidity removal efficiency up to 97.35% at 50 minutes treatment time compared to 91.85 % at 30 minutes after the treatment time. Again the most efficient settling time was observed.
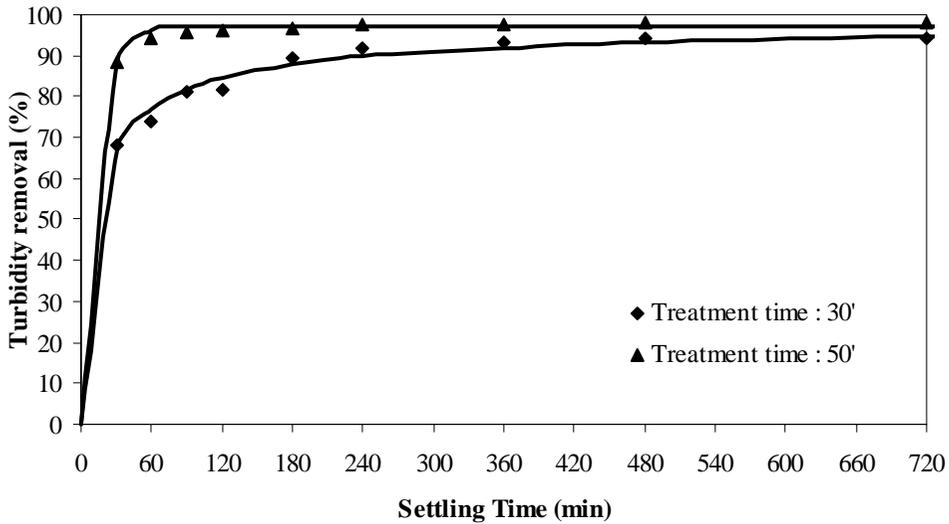

Figure 5: Effect of EC time on turbidity removal at DC of 0.8 A
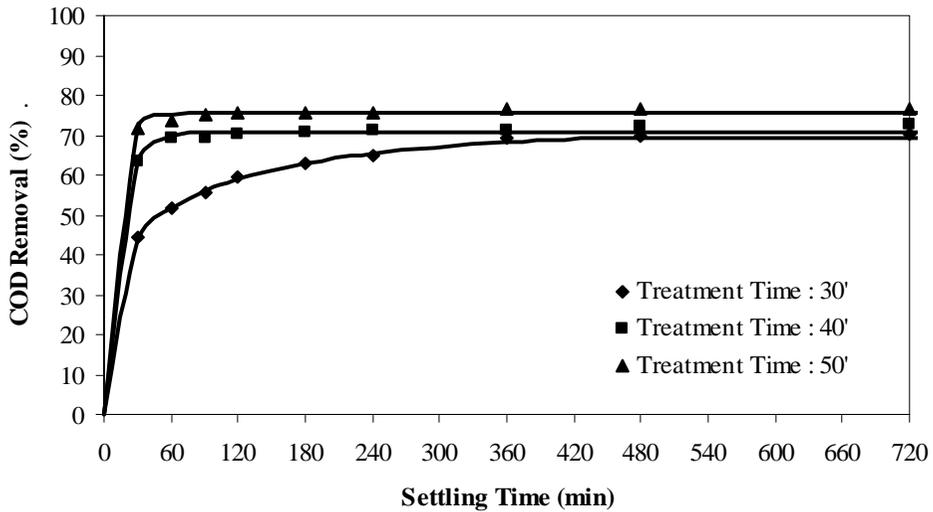
Figure 6: Effect of EC time on COD removal at DC of 0.8 A

3.4   COD Removal

As shown in Figure 6, the COD removal performance increases with the increasing treatment time. The COD was reduced by 75.79% (from 1140 to 276 mg/L) at 50 minutes treatment time compared to 71.05% at 40 minutes and 61.91 % at 30 minutes. These values were obtained at 240 minutes settling time.

4.0   Conclusions

Laboratories studies on the application of EC mechanism in removing SS of wastewater has found that:
- The EC process could enhance the SS, turbidity and COD removal efficiencies.
- The optimum treatment time for removing SS, turbidity and COD were 50 minutes.

With such preliminary finding, the EC process can be considered as a treatment option to enhance the separation of SS from wastewater via particles collision and agglomeration resulted from the increased in ionic charge.

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. *Environmental Progress,* 22 (1): 57 – 65.

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

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

Chen, G. (2004). Electrochemical technologies in wastewater treatment. *Separation and Purification Technology*, 38: 11 – 41.

Daneshvar, N., Sorkhabi, H.A. and Tizpar, A. (2003) Decolorization of orange II by electrocoagulation method. *Separation and Purification Technology*, 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. *Journal of Hazardous Materials*, 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. *Journal of Hazardous Materials*, B129: 116 – 122.

Holt, P.K., Barton, G.W. and Mitchell, C.A. (2005) The future for electrocoagulation as localised water treatment technology. *Chemosphere*, 59: 355 – 367.

Kobya, M., Can, O.T. and Bayramoglu, M. (2003) Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes. *Journal of Hazardous Materials*, B100: 163 – 178.

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

Lin, S. H., Shyu, C. T., and Sun, M. C. (1998) Saline Wastewater Treatment By Electrochemical Method. *Water Research*, 32 (4): 1059 – 1066.

Mollah, M. Y. A., Schennach, R., Parga, J. R. and Cocke, D. L. (2001) Electrocoagulation (EC) – Science and applications. *Journal of Hazardous Materials*, 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. *Journal of Hazardous Materials*, B114: 199 – 210.

Pathak, S.R. (2003) *Design and optimization of electrocoagulation reactor*. Master thesis, Lamar University.