Combined Magnetic Field and Electrocoagulation Process for Suspended Solid Removal from Wastewater

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Abstract

Innovative, cheap and effective methods of purifying and cleaning wastewater before discharging into any other water systems are needed. This paper study combined magnetic field and EC technology for removal suspended solid in wastewater treatment. The synthetic wastewater was treated in a batch mode by magnetic field combined with electrocoagulation. Wastewater sample was prepared from milk powder with a concentration of 700 mg/L. In the laboratory batch electrochemical cell, two monopolar iron (Fe) plate anodes and cathodes were employed as electrodes. DC current was varied fom 0.5 – 1 A, and operating time between 30 – 480 minutes. Three permanent magnets with different strengths were used in this experiment, namely NdFeB of 0.55T, SmCo of 0.16T and AlNiCo of 0.08T. The results showed that combined magnetic field and EC process has improved suspended solid removal from wastewater compared to EC process alone. The suspended solid and turbidity removals were as high as 92.3 % and 81.25 % with the combined process, while for EC process was as high as 89.3 % and 75.16 %.

Keywords : wastewater, electrocoagulation, magnetic field, suspended solid.

1.0   Introduction

A wide range of wastewater treatment techniques are known which include biological processes and physicochemical processes. A host of very promising techniques based on electrochemical technology are being developed and existing ones improved that do not require chemical additions [1]. These include *electrocoagulation (EC)*, *electroflotation (EF)*, *electrodeposition (ED)*, *electrooxidation (EO)*, and others [2]. Even though one of these, electrocoagulation, has reached profitable commercialization, it has received very little scientific attention [1].

Electrocoagulation (EC) is not a new technology [3]. Treatment of wastewater by EC has been practiced for most of the 20th century with limited success [4]. Using 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[2]. The principle of EC was used to treat bilge water from ships was first patented in 1906 by A. E. Dietrich [5].

EC has been used for the treatment of wastewater by various authors, and several differences were found in comparison to the chemical coagulation process. A literature survey indicates that EC is an efficient treatment process for different wastes, e.g. soluble oils, liquid from the

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food, textile industries, or cellulose and effluents from the paper industry [6 - 10]. EC is an effective process for the destabilisation of finely dispersed particles by removing hydrocarbons, greases, suspended solids and heavy metals from different types of wastewater [6 & 7]. According to Can et al. (2006) [11], EC has been proposed in recent years 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.

Aluminium or iron is usually used as electrodes and their cations are generated by dissolution of sacrificial anodes upon the application of a direct current [6]. Kobya et al. has investigated EC technologies to the treatment of textile wastewaters using iron and aluminum electrode materials [12]. The results showed that iron is superior to aluminum as sacrificial electrode material, from COD removal efficiency and energy consumption points.

The scientific explanation of magnetic water treatment has been the subject of investigation by British, Russian and American researchers. These studies involved the formation of scale and the methods for its prevention [13]. Magnetic treatment of water was first patented by Vermeiren in Belgium in 1945, and he is recognised as the discoverer of the fact that magnetic fields affect water. Magnetic treatment of water is an attractively simple approach by which the water to be treated flows through a magnetic field, and consequently changes some of its physicochemical properties.

Florenstano, et al. (1996) concluded that only the mineral content i.e., TDS (Total Dissolved Solids) that builds up after water is contacted with magnetic fields [13]. Faseur and Vanbrabant (1987) developed a continuous electromagnetic sedimentation tank in wastewater treatment to enhance the settling velocity of suspended particles) [14]. Another researcher, VanVelsen (1990) [15], has also developed a very efficient magnet for wastewater treatment. Johan Sohaili, et al. (2004) explained that, magnetic technology is a promising treatment process that can enhance the separation of suspended particles from the sewage) [16].

Among different physical and chemical methods of water and wastewater treatments; magnetic methods attract a special attention due to their ecological purity, safety, simplicity and less operating costs. Alteration of physical and chemical properties of water-dispersed systems in the mode of magnetic treatment implies a certain influence of magnetic field on the structure of water and aqueous solutions. Previous researches made by several scientific societies has discovered that magnetic field can improve technological characteristics of the water, i.e. better salt solubility, kinetic changes in salt crystallization and accelerated colloidal coagulation. Magnetic field is known to create the asymmetry of hydrated shells due to its effect on water molecules situated around the charged particles (colloid). Exposure to magnetic field would lead to higher electro-kinetic movement among the colloid. This will definitely increase the probability of attracting particles to cloak with one another. The theory of magnetic field impact on technological processes for water treatment falls into two main categories, crystallization at magnetic water preparation and impurity coagulation in water systems [17].

The objective of the present study is to examine the feasibility of EC and magnetic field in treating wastewater, to determine the optimal operational conditions and to establish which iron hydroxide, formed during electrolysis combined with magnetic field. This research is mainly focused on the capability of magnetic field and EC technology to remove and increase the sedimentation of suspended solid through static processing methods.

2.0   Background

2.1   C with Iron Electrodes

EC is an electrochemical wastewater treatment technology that is currently experiencing both increased popularity and considerable technical improvements. EC is a complicated process involving many chemical and physical phenomena that use consumable electrodes to supply ions into the wastewater stream [18]. Principle of EC (see Fig. 1) is cations generated by dissolution of sacrificial anodes induce flocculation of the dispersed pollutants contained by zeta potential reduction system [8 & 18].
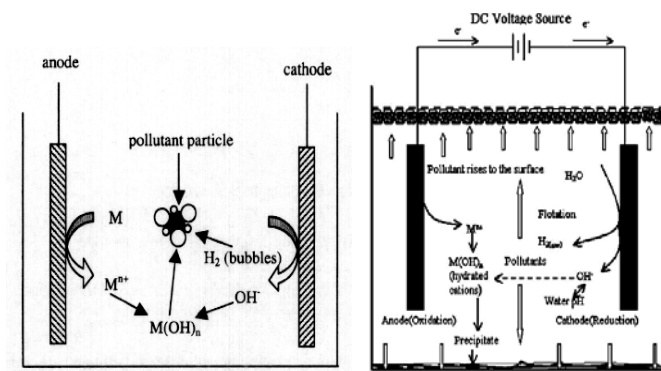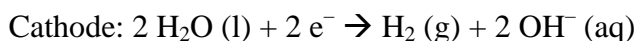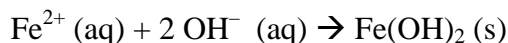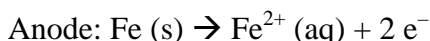

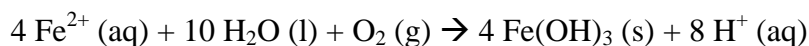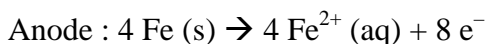Figure 1   Principle of electrocoagulation [8 & 18].

Lin et al., (1998) explained that the mechanism of the Electrochemical process in aqueous systems is quite complex [19]. It is generally believed that there are three possible mechanisms involved in the process: electro-coagulation, electro-flotation and electro-oxidation.
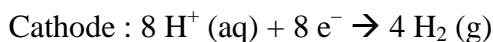
In EC with electrical current flowing between two electrodes, coagulant is generated in situ by electrolytic oxidation of the anode material. With an iron anode, $Fe(OH)_n$ with n = 2 or 3 is formed at the anode. Simplified oxidation and reduction mechanisms at the anode and cathode of the iron electrodes are represented by [1, 4, 9, 20, & 21]:

(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 : $4 Fe (s) + 10 H_2O (l) + O_2 (g) \rightarrow 4 Fe(OH)_3 (s) + 4 H_2 (g)$
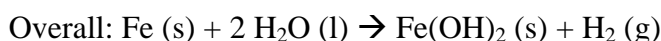
According to Larue et al. (2003), the generation of iron hydroxides (Fe(OH)n) is followed by an electrophoretic concentration of colloids (usually negatively charged) in the region close to the anode. Particles interact with the iron hydroxides and are removed either by surface complexation or electrostatic attraction [1, 4, 20, & 21].

2.2   Magnetic water treatment

The efficiency and effectiveness of magnetic water treatment is strongly affected by the chemical properties of the water, by the magnetic fields strength and by the fluid flow characteristics [16 & 22].Water is called as universal solvent because of its ability to dissolve, to some extent, almost any inorganic and many organic substances with which it comes to contact. The positive portion of the water molecule attracts negative particles or the negative end of other polar particles with the negative portion attracts positive particles or the positive end of other polar particles.

A magnetic field can be produced by aligning the positives and negatives to opposite ends of any magnetic material. The material used and the type of equipment utilized will determine the strength of the magnetic field. The stronger the magnetic field, the greater the number of dipoles pointing in the direction of the field. Under the influence of a given magnetic field, the charges separate until the restoring forces vary on magnitude from one kind of molecule to another with proportionate differences in the displacement produced by a given field.
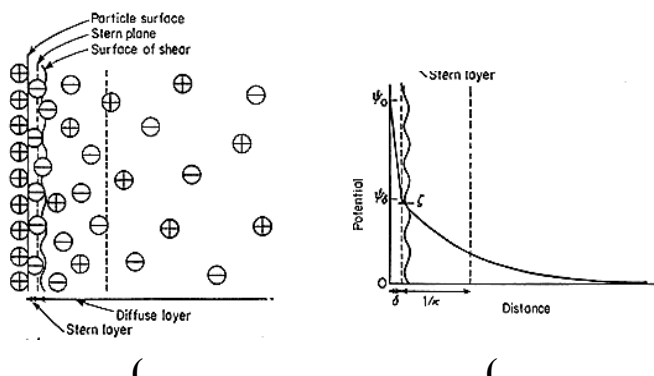

Figure 2   Electrical Double Layer Schematic (A) and Schematic representation of potential curves (B) [23].

Table 1   Composition of milk powder

Nutrient	Unit	Per 100 g
Energy	Kcal	494
Protein	g	24.5
Carbohydrate	g	36.0
Milk Fat	g	28
Calcium	mg	900

Colloidal particles in water carry a surface charge, and this charge is affected by pH and electrolyte content. Solid particle surfaces acquire charge through the following three mechanisms: chemical reaction at the surface, isomorphous replacement of ions within the solid crystal and adsorption of a surfactant ion. Colloidal suspended particles carry a surface charge, and this charge is affected by the imposed magnetic fields. The surface charge on the particles is compensated by attraction of counter ions to the surface in the form of a diffuse layer, resulting from thermal motions of ions in the solution. The electric state of the surface is known as an electric double layer (Fig. 2A). A fixed charge is attached to the solid surface and another layer of charge is diffused or distributed in the liquid in contact with the surface. As shown in Figure 2B, the concentration of cations (or anions) is not balance by anions (or cations) resulting in an electrical potential that decreases away from the surface as it decreases exponentially away from the fixed layer [24].

2.0   Materials and Methods

2.1   Wastewater characteristics

Fluid wastewater sample prepared from milk with a concentration of 700 mg/L and treated by using acetic acid (vinegar) as pH adjustment and electrolyte. The content of the milk powder as mixture of fluid wastewater is shown in Table 1. Concentration of acetic acid in this fluid was 150 mL/L (15 %) and the maximum electrical current of 1.2 A at the voltage 30 V. The current density was adjusted to a desired value and the coagulation was started.

2.2   Experimental setup

For EC tests, the monopolar iron (Fe) plate electrodes (130 x 50 x 4 mm) were used and the spacing between both electrodes was 50 mm. Electrodes were placed in two litres of fluid wastewater and connected to terminals of a DC Power Supply (LODESTAR 8107; 30V / 10A) with potensiostatic or galvanostatic operational options. The DC current was kept constant at 0.2A, 0.5A and 1.0A. Three permanent magnets with different strengths were used in this experiment, namely NdFeB of 0.55T, SmCo of 0.16T and AlNiCo of 0.08T. All magnets are cubic-shape rare earth permanent magnet size (50 mm x 50 mm x 20 mm).

The experiments carried out in this work were setup into static methods. EC and fluid wastewater batch tests were performed in a cylindrical glass cell (volume 2000 mL) and stirred at constant speed (Fig. 3). Stirring was provided by a plate impeller from plastic material ($\varnothing$ 3 cm) at a rotating velocity of 100 rpm. A cubic-shaped permanent magnet was attached under the glass cell. During each 30 minute runs, the effects of relevant wastewater characteristics such as pH, turbidity and suspended solid (SS) removal efficiencies were explored.
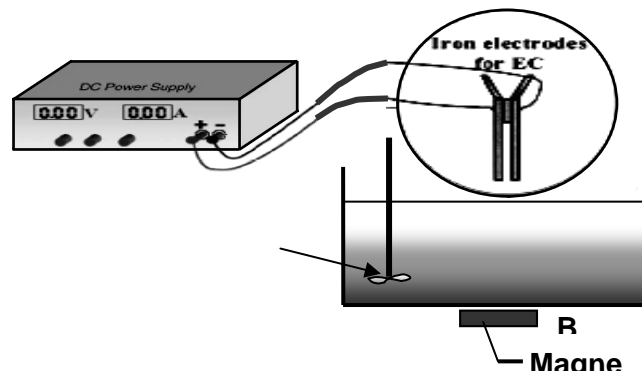
Figure 3 Static system apparatus

2.3 *Analytical procedure*

The pH of the solutions was measured by pH meter (Thermo Orion Model 420 A+). Thermal analysis was performed and equipped using HANNA Instrument Checktemp HI-98501. During each 30 minute runs, the sample was analyzed. The turbidity removal was measured from wastewater samples by using HACH DR/4000 (HACH Method 10047).

To measure TSS, the wastewater samples were filtered through a standard GF/F glass fiber filter. The residue retained on the filter was dried in an oven at 103^0C to 105^0C until the weight of the filter remains unchanged. The increase in the 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 the formula [21]:

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

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 change during the process*

In this batch experiment, the values of current were 0.2 A, 0.5 A and 1.0 A. Comparison of pH change during the process without magnetic filed is shown in figure 4. While comparison of pH changes between EC process (without magnetic field) and combined magnetic field plus EC, is presented in Figure 5. Generally, the pH of the medium varied during the process, as observed also by other investigators [12 & 25]. As can be seen from figure 4 and figure 5, the pH increases as the time of EC process is increased.
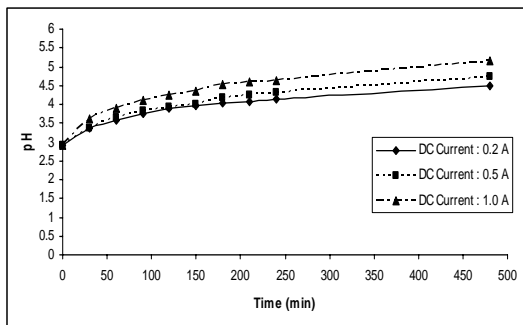
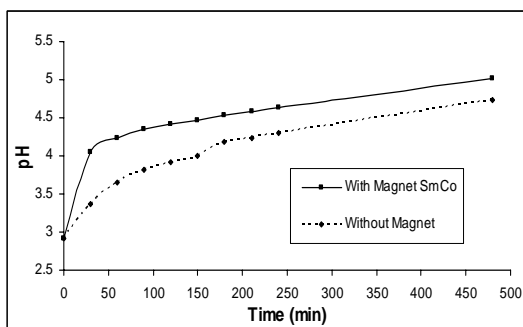Figure 4   pH change during the EC process (without magnetic field)

Figure 5   Comparison of pH change between EC process and EC-Magnet at DC current 0.5 A

3.2   Suspended solid removal

Figure 6 presents the effects of operating time and DC current on Suspended Solid (SS) removal during EC process without magnetic fields. Evidently, the SS removal increases as the operating time is increased. With an addition of DC current from 0.2 A to 1 A, SS removal increases from 85.83% to 91.52% in 480 minute. In addition, electroflotation and electro-oxidation processes occur when the operating time is between 0 – 210 minute.

Figure 7 shows that, a better SS removal was obtained during electrolysis with magnetic field compared electrolysis without magnetic field. At DC current of 0.5 Ampere, the SS removal is as high as 92.3 % for the combined process, but only 89.3 % for electrolysis without magnetic field.
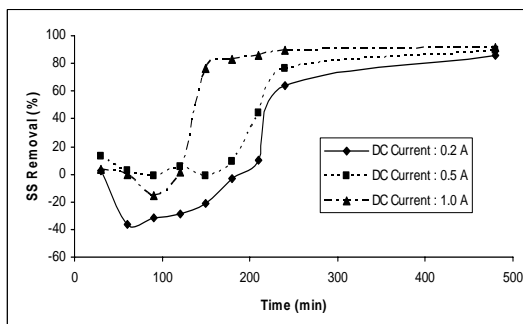

Figure 6   Removal of Suspended Solid (SS) in relation to DC current and operating time during EC process without magnetic field
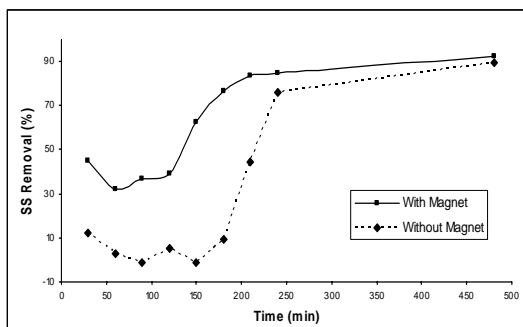
Figure 7   Comparison of SS removals, between EC process and EC-Magnet at DC current 0.5A

3.3   *Turbidity Removal*

The experimental results of the turbidity removal efficiencies are presented in Figure 8 and Figure 9. As it is depicted in Fig. 8, the turbidity removal increases from 480 NTU (initial turbidity) to 162 NTU (66.25%) for 480 minute operating time, at the electrical current (DC) 0.2 A. In comparison, at DC current of 1.0 A the turbidity removal increase further from 480 NTU in initial becomes 99 NTU (79.4 %) at 480 minute EC process. While as shown in Fig. 9, during electrolysis combined with magnetic fields at DC current of 0.5 Ampere, the turbidity removal efficiency is as high as 81.25 %, but only 75.16 % for EC process without magnetic field.
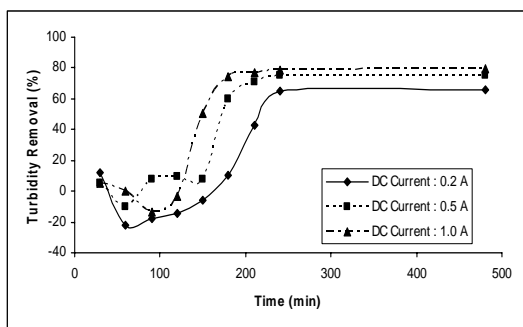

Figure 8   Effect of EC time on percentage of turbidity removal (without magnet)
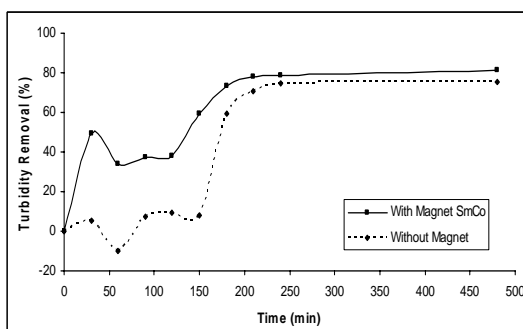

Figure 9   Comparison of turbidity removal, between EC process and EC-Magnet at DC current 0.5A

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4.0   Conclusions

This paper reports the preliminary stage of combined magnetic field and EC technology for the removal of suspended solid in wastewater treatment. To investigate the effects of magnetic field and EC, this research depends on four variables of SS (Suspended Solid) as following : DC Current (i), time (t), magnetic strength (B), and concentration (C). The results suggest that using the combined magnetic field plus EC process produced better overall results. The SS and turbidity removal are as high as 92.3 % and 81.25 % for the combined process, while for EC process was as high as 89.3 % and 75.16 %.

Acknowledgements

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