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Removal of dye by electrocoagulation method

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Abstract: The aim of study was designed to investigate removal of dye (reactive scarlet) by electrocoagulation using tubular iron electrodes. Experiments were conducted to examine the effects of the operating parameters, such as pH, current density and flow rate on dye and COD removal in the electrocoagulation process. The energy consumptions were also analyzed. COD of the wastewater was reduced from 620.4 to 21.5 mg/L with the removal efficiency of 96.5 % at the current density of 30 mA/cm^2, supporting electrolyte concentration of 0.1 M Na_2SO_4, and flow rate of 200 mL/min. The high dye removal efficiencies were obtained at all experiments. The initial dye concentration of 200 mg/L was reduced to 1.08 mg/L with the removal efficiency of 99.4 % at 30mA/cm^2 after 90 min electrocoagulation.

Keywords: Wastewater, COD, Electrode, Decolourization, Electrolysis

1. Introduction

To generate clean water to the majority of population around the world is the most important challenge facing humanity today [1]. Billions of liters of industrial wastewater are produced everyday [2]. The pollution induced by dyestuff losses and discharge during dying and finishing processes in the textile industry has been a serious environmental problem for years [3]. Dyestuffs are organic compounds which are in solution or in suspension form to react with objects surfaces in chemical or physico-chemical ways. These reactions then change the surface structure of the objects. Color in water bodies effect aquatic diversity by blocking the passage of sunlight. Further, a color in water bodies has an adverse aesthetic effect. Since many organic dyes are harmful to human beings, the removal of color from process or waste effluents becomes environmentally important. Reactive dyes are extensively used in textile industry, fundamentally due to the ability of their reactive groups to bind to textile fibers by covalent bonds formation [4]. Various treatment methods including, physical, physico-chemical and chemical processes have been investigated for treating dye bearing effluents. All these methods have different color removal capabilities, capital costs and operating rates. The system arrangement of electrocoagulation method is shown in Fig. 1.

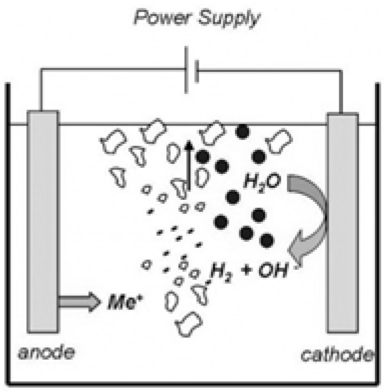

Figure 1. *Arrangements of electrochemical reactor*

Electrocoagulation (EC) is an alternative technology for wastewater treatment and recovery of valuable chemicals from wastewater [5]. This method involves a sacrificial anode, usually aluminum or iron, where the coagulating metal cations are released in situ as long as an electrical current is applied [6]. Treatment of wastewater by EC was practiced for most of the past century with limited success and popularity. However, in the last few years, its usage has been increased as the technology has been improved to minimize electrical power consumption and maximize effluent throughput rates [7]. EC compared with traditional flocculation and coagulation, has, in theory, the advantage of removing small colloidal particles; they have a larger probability of being coagulated because of the electric field that sets them in motion. Addition of excessive amount of coagulants can be avoided, due to their in situ generation by electro-oxidation of a sacrificial anode. EC equipment is simple and easy to operate. Short reaction time and low sludge production are two other advantages of the technique [4].

During last few decades, EC using various electrode materials such as cast iron, stainless steel, aluminum or graphite have been successfully applied to "hard" industrial wastewater [8].

The reactions which occur at iron electrode in situ shown in Table 1.

Table 1. *Reactions occur at iron electrode [9].*

Mechanism 1		**Mechanism 2**
$4Fe_{(s)} \rightarrow 4Fe_{(aq)}^{2+} + 8e^-$	Anode	$Fe_{(s)} \rightarrow Fe_{(aq)}^{2+} + 2e^-$
$4Fe_{(aq)}^{2+} + 10H_2O_{(l)} + O_{2(g)} \rightarrow 4Fe(OH)_{3(s)} + 8H_{(aq)}^+$	In the solution	$Fe_{(aq)}^{2+} + 2OH_{(aq)}^- \rightarrow Fe(OH)_{2(s)}$
$8H_{(aq)}^+ + 8e^- \rightarrow 4H_{2(g)}$	Cathode	$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH_{(aq)}^-$

The objective of this study to perform the best treatment parameters using iron electrodes in EC process in a semi continuous flow by changing various experimental parameters such as flow rate, initial pH and current density. COD and dye concentrations were analyzed and energy consumption per m3 of wastewater treated was calculated.

2. Materials and Methods

2.1. Wastewater

To simulate a textile wastewater, 0.5 L of model wastewater was prepared using required amount of reactive scarlet dye. The initial parameters of wastewater are mention in Table 2. Wastewater was feed to the reactor semi continuously in a desired feed rate using a digital peristaltic pump.

Table 2. *Initial Parameters of Wastewater*

Parameter	Unit	Value
pH		7.1
COD	mg/L	620.4
Dye Concentration	mg/L	200

2.2. Reactor

The iron cylindrical reactor with a height of 40 cm and diameter of 3.5 cm was used as cathode while the three pairs of iron rods (o.d. = 1.25cm, height:34 cm) were used as anode and placed in the centre of the reactor.

2.3. Sampling and Analysis

Samples were taken with 10 minutes interval from the reactor to determining COD and dye concentrations. The samples were centrifuged and the residual dye concentration in the supernatant was determined. The dye concentrations were determined from their absorbance characteristics in the UV–vis range (200–800 nm) with the calibration method using spectrophotometer. For these measurements, the maximum adsorption (λmax) wavelength of dyes was determined as 510 nm by measuring their absorbance at various wavelengths. The COD concentrations were determined by a titrimetric method after digestion of the sample for 2 hours at 150 ^{0}C by a Hach COD Digestion Reagent.

The removal efficiency has calculated as;

Removal Efficiency (%) =

$$\frac{(C_0 - C)}{C_0} x100 \qquad (1)$$

Where;

C_0 : Initial concentration (mg/L); C : Concentration at t (mg/L)

Energy consumption per m^3 of wastewater treated has calculated as follows;

Energy Consumption (kWh/m^3)

$$\frac{U\ I\ t\ \frac{1kW}{10^3W}}{V_W} \qquad (2)$$

Where;

U : Cell voltage (v)

I : Current (A)

t : Time (h)

V_W : Volume of wastewater (m^3)

3. Results and Discussions

3.1. Effect of Current Density

The current density is the amount of current per area of the electrode. It is an important parameter in removal efficiencies. At higher current density, the amount of metal oxidized increased, resulting in a greater amount of hydroxide flocs for the removal of pollutants. Furthermore, the bubbles density increased and their size decreased with the increasing of cell current, resulting in a faster removal of pollutants [10]. Applied current density directly affects process performance and operating costs [11]. The effect of current density was investigated using 10, 20 and 30 mA/cm^2 at 0.1M Na_2SO_4. The removal efficiency of COD increased significantly with increase of current density as seen in Fig.2. The COD removal efficiencies of 78.6, 91.3 and 96.5% were obtained at 10, 20 and 30 mA/cm^2 respectively. The initial COD of 620.4mg/L was reduced to

21.5mg/L at 30 mA/cm^2 after 90 min electrocoagulation. According to Turkish Directive on Water Pollution Control [12], the discharge limit of COD for textile wastewaters is 200 mg/L. By these treatment values the limit can be achieved. Dye concentrations were reduced more then 90 % at all current density within 10 minutes of retention time as can be seen in Fig. 3. As a result of increasing current density the electrical energy consumptions and operational costs also increases directly (Fig.4.). The electrical energy consumption at 10 mA/cm^2 was 32.94 kWh/m^3.

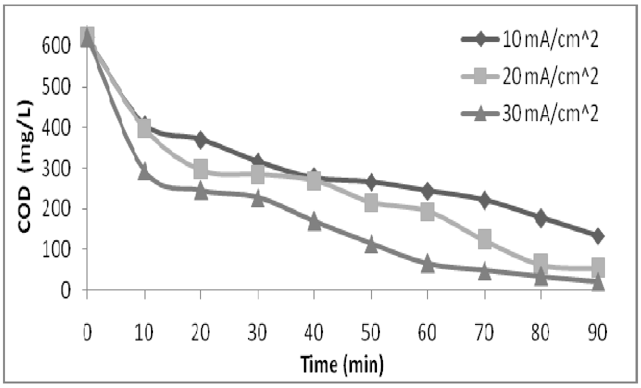

***Figure 2.** Effect of Current Density on COD*

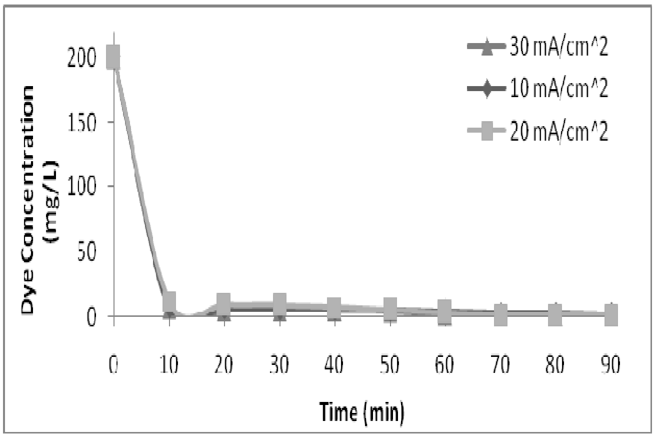

***Figure 3.** Effect of Current Density on Dye Concentration*

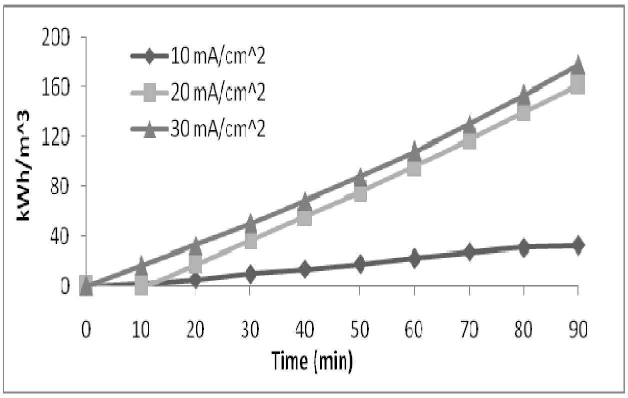

***Figure 4.** Effect of Current Density on Energy Consumption*

3.2. Effect of Initial pH

The pH is one of the most important factors affecting the performance of electrochemical process. The pH of raw wastewater can have either a positive or a negative influence on the treatment efficiency as it affects the stability of various hydroxide species that are formed [9]. The effects of initial pH on COD removal from wastewater using iron electrodes by electrocoagulation was investigated using current density of 30 mA/cm^2 and 0.1 M Na_2SO_4 concentration. The COD removal efficiencies of 75.0 % at pH 5, 96.5 % at pH 7.1, 79.7 % at pH 9 were achieved. The final COD concentrations were 155, 21.5 and 126 mg/L at pH 5, 7.1 and 9 respectively as seen in Fig. 5. Original pH (7.1) of wastewater can be seen as optimum pH for the treatment. Fig. 6 shows the reduction of dye concentrations during process. As noticed in Fig. 6, short operation time can be applied.

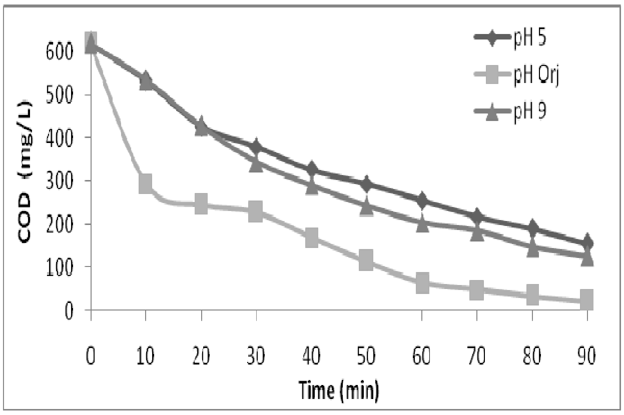

***Figure 5.** Effect of pH on COD*

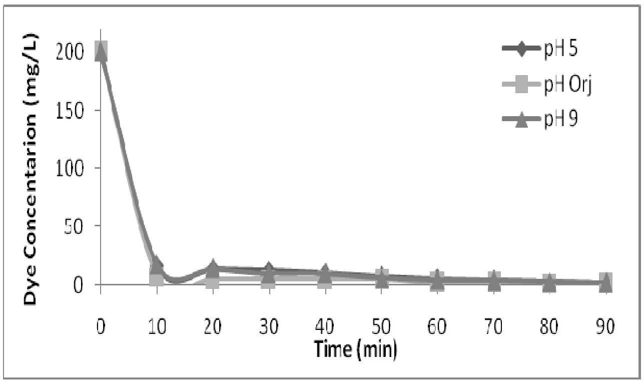

***Figure 6.** Effect of pH on dye concentration*

3.3. Effect of Flow Rate

The wastewater flow rate was examined at 100, 200 and 400 mL/min at current density of 30 mA/cm^2. As shown in Fig. 7 the COD removal efficiencies of 87.4, 96.5 and 68.8 % were obtained after 90 min. electrocoagulation at 100, 200 and 400 mL/min respectively. The initial dye concentration of 200 mg/L was reduced to 1.24, 1.08 and 3.52 mg/L at 100, 200 and 400 mL/min respectively that can be seen on Fig. 8. As in all experiments, the dye concentrations were reduced over 90% in a short EC time.

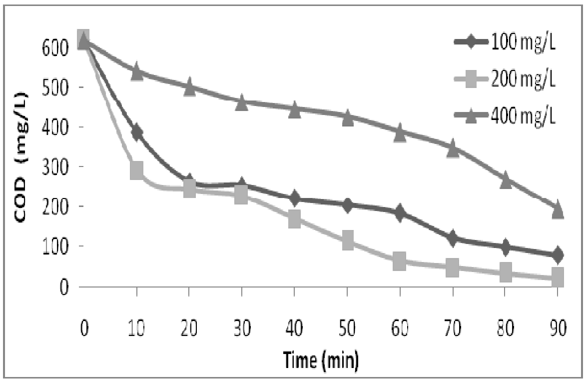

Figure 7. *Effect of flow rate on COD*

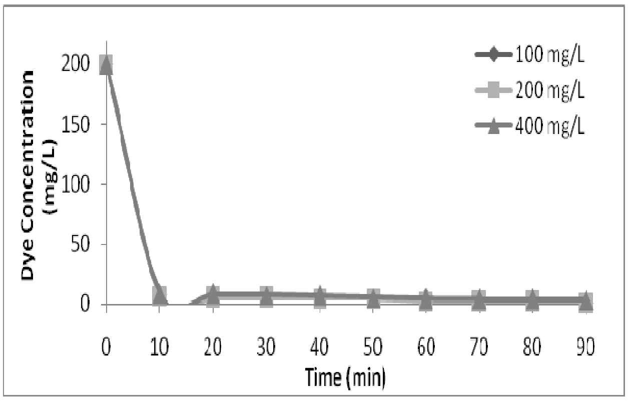

Figure 8. *Effect of flow rate on dye concentration*

4. Conclusions

The results obtained in this study shows that color can be eliminated with high percentages and high COD removal efficiencies can be achieved using our unique design of electrocoagulator. The effect of current density on removal of COD can clearly be understood. As the current density increased the removal of organic matter was also increased. In all cases, dye removal efficiencies were greater than 90 % in short period of operational time. It is also known that, the increase on the current density means the increase on energy consumption. So an optimum current density has to be considered due to local discharge limits, energy consumptions, local energy unit prices and some other limiting factors. In addition, this study showed that the original pH of the wastewater was the best. The effect of flow rate is an important issue.

Overall, high removal efficiency of reactive scarlet was obtained using tubular iron electrodes. The electrocoagulation process has the potential to treat the textile wastewater and thus to reduce the contamination of the environment by the dye molecules.

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