

Electrocoagulation Removal of Sunset Yellow Dye from Aqueous Solution Using Aluminum Electrode

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Abstract

Electrocoagulation (EC) is a technique in which a sacrificial electrode is used to induce the synthesis of certain coagulants. It's a straightforward and cost-effective solution. This makes it a popular method for removing contaminants from water and wastewater. The EC unit with two aluminium metal electrodes is used in this procedure. To remove the dye Sunset Yellow from aqueous solution, we set out to create a novel EC using aluminium electrodes as an anode. Direct current removal of the dye was used to verify the method's efficacy, and the effects of the applied current density were taken into account. The effects of pH, starting dye concentration, and electrolysis time were explored and adjusted for.

Key words: sunset yellow, electrocoagulation, dye, removal.

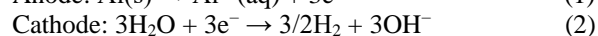
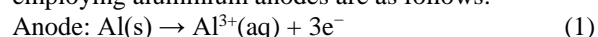
1. Introduction

The electrochemical treatment of complex wastewater streams is one of the promising approaches. A number of industrial wastewater contaminants have been successfully removed using electrochemical methods, such as electrolysis and electrocoagulation [1,2]. Different oxidation, reduction, and decomposition processes have been documented in the past for the electrolysis process; on the other hand, diverse mechanisms for removal have been reported in the past for the process of electrocoagulation [3]. Metal hydroxide flocs related to the anode material can be produced by electrocoagulation using aluminium or iron anodes that have been sacrificed for this purpose.

When it comes to the treatment of both drinking water and wastewater, electrocoagulation (EC) is a basic but extremely effective option. As a result, it has not been extensively adopted due of its high starting price. Environmental regulations on effluent wastewater are becoming more stringent, and electrocoagulation has recently attracted a lot of attention [4-6]. Water containing nitrate and arsenic as well as potable water has all been effectively treated using the electrocoagulation approach [7, 8, 9] and effluents from the pharmaceutical industry [8, 8]. Wastewater from dyeing companies has been suggested to be treated well using EC [11]. At various operating conditions, laboratory-scale treatment experiments with textile dye-containing industrial wastewater samples have shown promising removal of COD, colour, turbidity, and the total dissolved solids (TDS) [12–14]. Electroplating, industrial, food, pulp, dyeing and printing, and groundwater treatment are just a few of the water treatment industries where EC technology has been used recently [15–17]. Research shows that electrocoagulation has a reasonably high rate of reduction in critical parameters like as turbidity, chemical and biochemical oxygen demand (COD and BOD). Several types of contaminants, including organic pollutants, can be successfully removed by electrocoagulation, according to published research. An advantage of the electrocoagulation method is that it combines flocculation with air

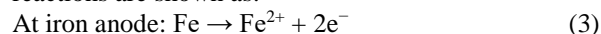
flotation without the need for additional chemical agents, therefore avoiding secondary contamination. The electrocoagulation device employed in most cases is very simple, requiring little space, and its operation is reasonably simple [18,19]. There are a number of sequential processes to electrocoagulation, including the production of low-soluble coagulants in the water, the removal of colloidal or soluble contaminants from the coagulants, and the removal of the coagulants by sedimentation or flotation. Metal ions are formed at the anode as a result of metal dissolution, while hydrogen gas is liberated at the cathode surface under the effect of flowing current. The hydrogen gas created at the cathode would also aid in the removal of the particles from the water.

Depending on the type of anodic material, the EC reactor experiences a variety of reactions. The primary reactions that take place at the electrode when employing aluminium anodes are as follows:



Al^{3+} ions and OH^{-} ions generated by the electrode reactions (1) and (2) react to form various monomeric species such as $\text{Al}(\text{OH})_2^{+}$, $\text{Al}(\text{OH})_2^{4+}$, $\text{Al}(\text{OH})_4^{-}$, and polymeric species such as $\text{Al}_6(\text{OH})_{15}^{3+}$, $\text{Al}_7(\text{OH})_{17}^{4+}$, $\text{Al}_8(\text{OH})_{20}^{4+}$, $\text{Al}_{13}\text{O}_4(\text{OH})_{24}^{7+}$, $\text{Al}_{13}(\text{OH})_{34}^{3+}$, which transformed finally into $\text{Al}(\text{OH})_3(\text{s})$ according to complex precipitation kinetics [21].

When iron is used as anode [22,23], the expected reactions are shown as:



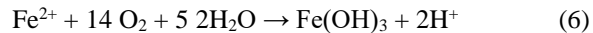
Also, in acidic pH solutions, the electrode is attacked by H^{+} and enhances its dissolution by following reaction:



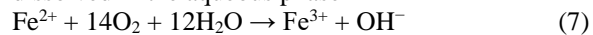
Under alkaline condition:



Under acidic condition:



Ferrous ions are oxidized to ferric ions by oxygen dissolved in the aqueous phase



The oxygen evolution reaction may also take place at anode surface and is represented as:



At cathode, following reduction reaction takes place:



Anodic passivation, manifested as a rise in anode potential, is a major issue in the EC process because it results from $\text{Al}_2\text{O}_3(\text{s})$ precipitation on the anode. It is usual practise to utilise electrodes of the same material, and if necessary to modify the polarity of the current, to reduce passivation [24]. Electrocoagulation will be tested as an alternate treatment approach for Sunset Yellow dye at concentrations ranging from 10 to 50 mg/L. On the extent to which dye removal is influenced by various characteristics such as applied current density, initial dye concentration and salinity, studies have been conducted.

2. Experimental

A 0.25 L glass vessel was used for electrocoagulation (EC). A bench-scale EC with a working volume of 100 mL was used in the experiment. The anode and cathode were both made of aluminium. The electrodes' working surface area was 2.42 cm² and they were cylindrical in shape. Electricity was generated via a direct current solar cell with a maximum voltage of 6.0 V and a current of 0.5 A. The solar cell was attached to the electrodes so that it could provide the voltage needed. Anode and cathode metal rods were stacked in parallel in the EC reactor. The reactor's contents were agitated at 100 rpm by a magnetic stirrer during EC. Room temperature EC studies were conducted with pH modification and addition of electrolytes. pH and supporting electrolytes were studied by adding either HCl or NaOH for pH adjustment and NaCl for solution conductivity management.

A UV-visible spectrophotometer was used to determine the dye clearance percentage and the absorbance at max (the wavelength that exhibits the greatest absorption). According to the formula, removing efficiency was determined as follows:

$$\text{Removal efficiency} = \frac{C_0 - C_t}{C_0} \times 100 \quad (10)$$

where C_0 and C_t are initial and concentrations (mg/L) at a given time.

After a definite period, the solution was withdrawn from the reactor vessel and centrifuged immediately for separation of any suspended solids. The solution was analyzed by a spectrophotometer by measuring the absorbance at 482 nm for Sunset Yellow (SY). The structure of SY dye is shown in Fig. 1.

Sunset Yellow (E 110) is a well-known synthetic azo dye used as a coloring agent for many kinds of beverages and variety of foods, including desserts, soups, cheeses, confectionary, sauces, and preserved fruits.

3. Results and Discussion

The impact of several parameters such electrocoagulation time, concentration of dye, current density, potential difference, salinity of electrolyte solution, distance between electrodes, and initial pH have been explored on the final Sunset Yellow dye removal efficiency. The dye clearance % was computed.

pH Affect

pH has a significant impact on the EC process and electrochemical reaction performance [25]. coagulants and dye molecules are affected by it. Acidic and basic pH levels have been chosen to study the influence of acidity on the removal of dyes. 0.1 M HCl solution and 0.1 M NaOH solution were used to modify the pH of the solutions. Figure 2 shows that pH values in the very low range are undesirable. Highest removal efficiency can be achieved at alkaline media. The amphoteric behaviour of metal hydroxides, which leads to the formation of soluble cations and monomeric anions, can explain the low removal efficiencies in more acidic solutions [26].

Conductivity of solution has an effect

Any electrolytic cell's voltage, current efficiency, and energy consumption are all affected by the conductivity of a solution. Fig. 3 shows the results of studies utilising a range of initial NaCl concentrations to determine the effect of water conductivity on the EC removal of SY dye. By increasing NaCl content from 1 to 2.5 g/L, the clearance percentage improved from 58.2 percent to 78.6 percent. Increased NaCl conductivity may be a factor in this behaviour, which has low resistance for current. A greater amount of metallic hydroxide was formed and dye removal was increased when the current was raised. Also, creation of hypochlorite ions at the anode produces an increase in the removal of dye due to the oxidation characteristics of hypochlorite ions produced [27]. NaCl content of 2.5 g/L was found to have a high colour removal percentage with low cell voltages and low energy usage.

Dye concentration has an effect on the colour

SY electrocoagulation removal is affected by dye concentrations ranging from 10 to 50 mg/L, as illustrated in Fig. 4. The first 15 minutes of the process demonstrated quick elimination of all concentrations. The elimination percent of the method reduced from 88.6 percent to 78.2 percent when the starting concentration increases from 10 to 50 mg/L. However, this drop in removal percentage is accompanied by an increase in removal capacity (mg/g). Figure 5 depicts the relationship between dye starting concentration and dye removal capability.

Voltage density has an effect

For 50 mg/L SY at optimal pH, several current densities (4.2-16.8 mA/cm²) were tested to see how they affected dye removal. The most essential operational factors in the EC process are the current density and the period of electrolysis, which determine the maximum removal and the ultimate running cost for the process. As can be seen in Fig. 6,

increasing the current density from 4.2 to 16.8 mA/cm² resulted in more dye clearance. Fresh electrode surface causes a significant rise in removal %, as depicted in the figure. While further aluminium cation additions result in amorphous aluminium hydroxide precipitating, this precipitation is followed by a precipitation mechanism that aggregates contaminants. Coagulated aggregates interact with gas bubbles in the reactor's final stage, causing them to float to the top or sink to the bottom.

In the context of kinetics,

In order to understand the removal process, kinetic parameters must be studied. Metal cations are formed in water as a result of the dissolving of electrode material during electrical current flow. As a result, current density is a significant factor in dye removal, and a kinetic study can help determine the removal rate over time.

It is used to analyse data on the rate of adsorption of dyes. Definition of the first-order Lagergran model

$$dq_t/dt = k_1(q_e - q_t) \quad (11)$$

where q_e is the amount of dye removed at equilibrium, q_t is the amount of dye removed at time t (min), and k_1 (min⁻¹) is the rate constant of first order. The integrated form of Eq. (11) can be written as:

$$\log(q_e - q_t) = \log q_e - k_1 t / 2.303 \quad (12)$$

The q_e and rate constant (k_1) could be calculated from the slope of the plot of $\log(q_e - q_t)$ versus time (t). A straight line obtained ($R^2 = 0.9475$) from the plot suggests that this plot is not applicable of this kinetic model. It was found that the calculated q_e

value do not agree with the experimental values (78.4 mg/L), so the removal does not obey the first-order kinetics adsorption.

The second-order kinetic model is expressed as [29]:

$$dq_t/dt = k_2(q_e - q_t)^2 \quad (13)$$

where k_2 is the rate constant of the second-order adsorption. The integrated form of Eq. (13) with the border conditions of $t=0$ to $t=t$ and $q_t=0$ to $q_t=q_t$ can be written as:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{1}{q_e}\right) t \quad (14)$$

where k_2 is defined as the value of equilibrium rate constant (g/mg/min). The values obtained for correlation coefficient of pseudo-second order model (Fig. 8) was found to be 0.9959 for SY which is higher than pseudo-first order. Compared to pseudo-first order equation, the pseudo-second order model can explain the biosorption kinetic behavior of SY by electrocoagulation.

Conclusion

Electrocoagulation with two aluminium electrodes was used to remove the sunset yellow dye. There was an investigation of the effects of dye concentration, acidity, salt content, current density, and electrolysis time. A set of ideal conditions for the removal was nailed down in advance. For a current density of 16.8 mA/cm² and 2.5 g/L NaCl, the optimal pH was found to be 9.5. To remove dyes from dirty water, the suggested process is cost-effective, rapid and energy efficient.

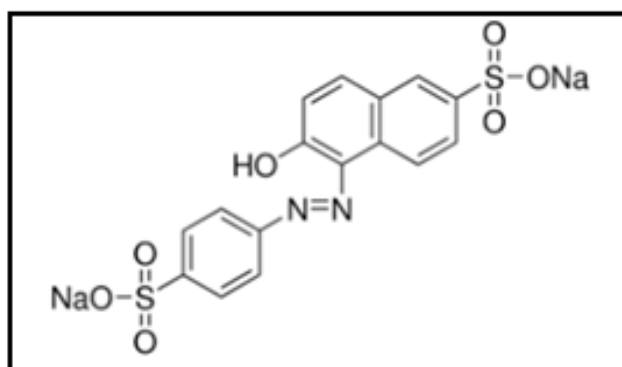


Fig. (1) Chemical structure of Sunset Yellow dye.

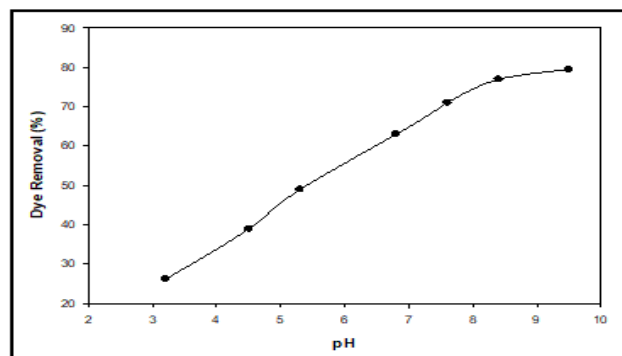


Fig. (2) Effect of pH on SY removal by EC. [SY = 50 mg/L, NaCl = 2.5 g/L]

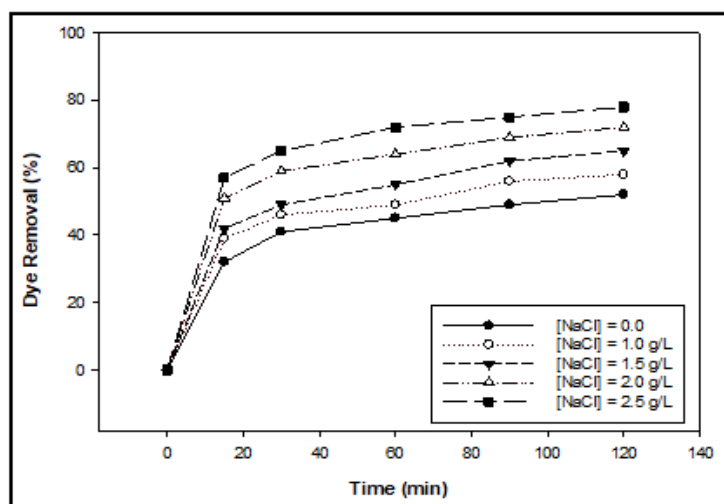


Fig. (3) Effect of conductivity on SY removal percent by EC. [SY = 50 mg/L, pH = 9.3]

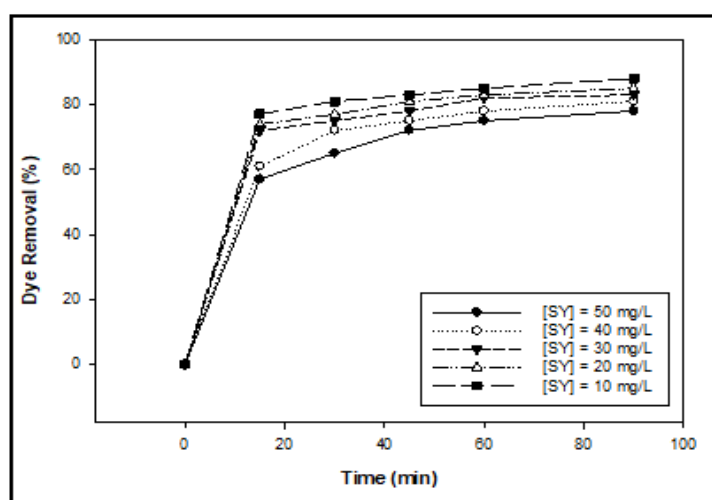


Fig. (4) Effect of dye concentration on SY removal percent by EC. [SY = 50 mg/L, pH = 9.3, NaCl = 2.5 g/L]

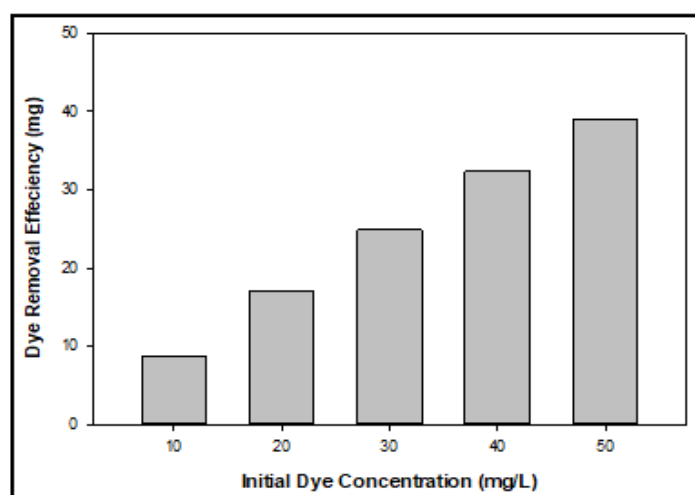


Fig. (5) Effect of dye concentration on SY removal efficiency by EC. [SY = 50 mg/L, pH = 9.3, NaCl = 2.5 g/L]

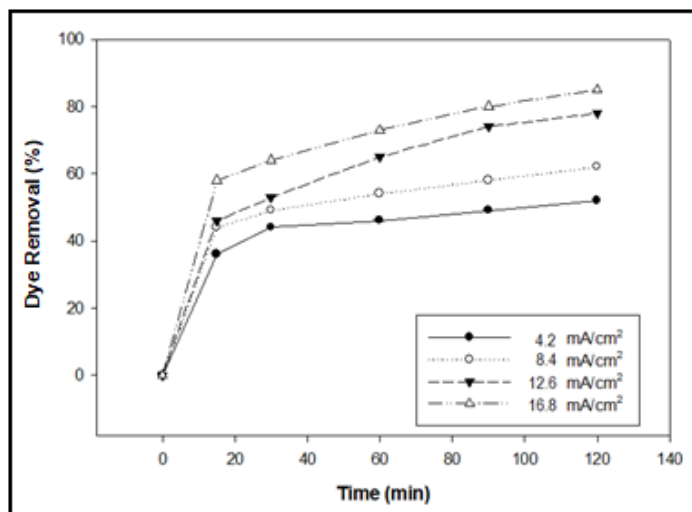


Fig. (6) Effect of current density on SY removal efficiency by EC. [SY = 50 mg/L, pH = 9.3, NaCl = 2.5 g/L]

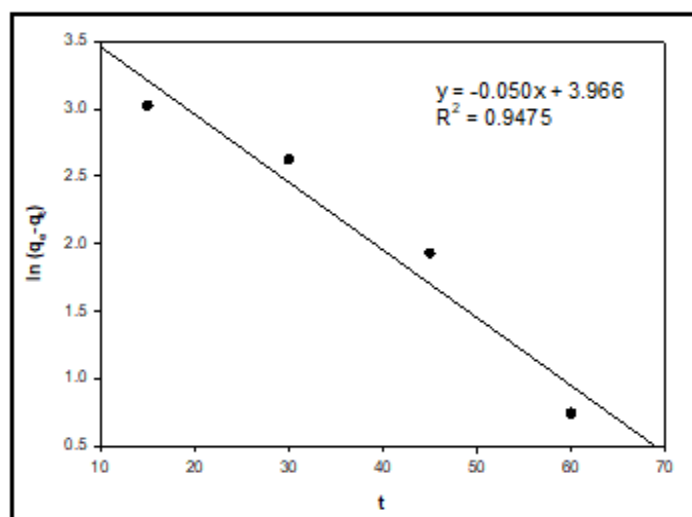


Fig. (7) Plot of first-order kinetic model for removal of SY by electrocoagulation.

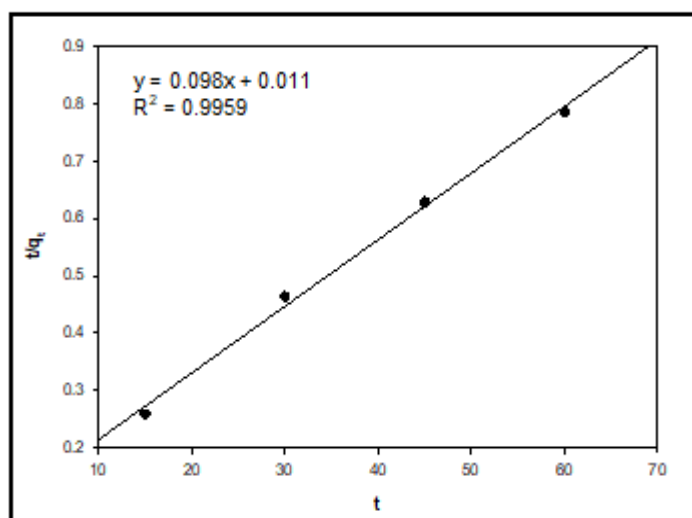


Fig. (8) Plot of second-order kinetic model for removal of SY by electrocoagulation.

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