Efficiency of Electrocoagulation for Removal of Reactive Yellow 14 from Aqueous Environments

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Background & Aims of the Study: Discharge of textile industry colored wastewater without enough treatment into natural water resources cause serious pollution. Most of the conventional wastewater treatment methods are not effective enough to remove these dyes from wastewater. In this study, efficiency of electrocoagulation process with iron electrodes for treatment of Reactive Yellow 14 dye from synthetic solution has been studied and concluded.

Materials & Methods: This experiment was conducted in a batch system with a volume of 2 L that had been equipped with 4 iron electrodes. The effect of operating parameters, such as voltage, time of reaction, initial dye concentration, and interelectrode distance on the dye removal efficiency was investigated.

Results: In optimum condition (pH 2, voltage 40 V, electrolysis time 25 min, and interelectrode distance 1 cm), electrocoagulation method was able to remove 99.27% of Reactive Yellow 14 from synthetic solution.

Conclusions: Electrocoagulation process by iron electrode is an efficient method for removal of reactive dyes from colored solution.

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Background

Textile factories produce considerable amounts of wastewater containing color, suspended particles, high pH, and high chemical oxygen demand (COD). These wastewaters are directly discharged into natural water streams and cause serious pollution problems that lead to endangerment of aquatic boiota (1). The great quantity of such wastewaters can be produced by textile, cosmetic, leather, plastics, paper, food, and mineral factories. Approximately 1 to 15% of the dye is lost in dyeing and finishing processes and is released into wastewater. The textile industry uses about 10,000 dyes and pigments (2,3). High color of the textile effluents is particularly troublesome because of its negative visual impact (4). Dye bath effluents spread color to streams and affect their aesthetic value. Color interferes with penetration of sunlight into water, retards photosynthesis, restrains the growth of aquatic biota, and interferes with gas solubility in water bodies. In other words, dye effluents may contain chemical components, which are toxic, carcinogenic, mutagenic, or even teratogenic for various microbiological and fish species (5).

The biological, chemical, and physical methods have been studied for dye removal, but the biological methods have not been very effective because of the non-biodegradable nature of most dyes (6). Several techniques exist for removal of dye-containing wastewater, such as precipitation, adsorption, photo-degradation (UV/H_2O_2 or UV/TiO_2, etc.), chemical oxidation (e.g., chlorination, ozonization), biodegradation, chemical coagulation–flocculation and electrocoagulation (EC). Chemical coagulation can add high concentration of chemical substances to effluent (5,6). Photo-oxidation by UV/H_2O_2 or UV/TiO_2 and Fenton oxidation needs additional chemicals, which can lead to secondary pollution (5–11). The adsorption process is one of the effective methods for removal of dyes from aqueous solution. Activated carbon is the most widely used adsorbent for dye removal (12).

In recent years, EC method has been created as an effective method for purification of various wastewaters. Although biodegradation process is cheaper than other methods, it is less effective because of toxic dyes that prevent bacterial growth (13,14). EC as an electrochemical process can overcome the drawbacks of conventional decolorization techniques, so, it is an attractive alternative method of textile dye treatment (15-18). EC process provides a simple, reliable, and cost-effective method for treatment of wastewater without any additional chemicals and secondary pollution. It also reduces the amount of waste sludge, which needs to be disposed. EC technique uses a direct current source between immersed metal electrodes and polluted water (2-6). This process by hydrolysis of iron hydroxide creates the flocks, which can destabilize and aggregate suspended particles or precipitates and absorb dissolved contaminants (19). EC has been successfully tested to treat decolorization of dye-containing solutions. The dye in such wastewaters is coagulated by iron (II) and aluminum hydrates or hydroxides produced from the sacrificial anode (16–19).

Aims of the study: In this study, removal of Reactive Yellow 14 (RY-14) dye from a synthetic solution was examined using EC, and compared with the data of our previous study (15,20). The RY-14 dye's chemical formula is $C_{20}H_{19}ClN_4Na_2O_{11}S_3$ with molecular weight of 669 g/mol. This comparison covers not only the key operating parameters common to EC and CA, such as the RY-14 dye concentration in wastewater before treatment, pH, water conductivity/ionic strength and retention/residence time, but also the specific parameters of each technique, including adsorbent dosage for CA and current density for EC. The optimum values of these parameters were primarily determined according to the yield of decolorization, but operating costs based on adsorbent dosage for CA and on electrode consumption and energy requirements for EC were also assessed for comparison.

Materials & Methods

Experimental procedure for electrocoagulation: All chemicals and reagents used in this study were of analytical reagent grade (Merck, Germany).

RY-14 solutions were prepared by dissolving stock solution in distilled water without pH adjustment. The batch experimental apparatus is shown in figure 1. This unit is constructed from an electrochemical reactor, a DC power supply, and iron electrodes. A cylindrical iron sheet lining the inner wall and the bottom of the vessel was used as anode, while a cylindrical iron screen cathode having geometry similar to the anode was placed at a distance of 1 cm from the anode and dipped in colored solution. The electrodes were placed in

1500 mL aqueous dye solutions in a 2000 mL plexiglas electrolytic reactor. There were four electrodes connected in a bipolar mode in the electrochemical reactor, each with a dimension of 10×15×0.2 cm. A Sunwa Electronics multimeter (ADAK model PS808, Iran) was used for measuring the current and the potential between the two electrodes. The electrodes were being washed by dilute HCl between the experiments. At the beginning of a run, a particular concentration of dye (mg/L) was feeded into the reactor, and its pH and conductivity was being adjusted using H_2SO_4, NaOH, and KCl. After EC process, particulates of colloidal ferric oxyhydroxides gave a yellow–brown color into the solution. Then sample was centrifuged (4000 rpm for 5 min). The dye concentrations were measured at λ_{max}=440 nm using a spectrophotometer (Shimadzu, Tokyo, Japan; Model 1601).

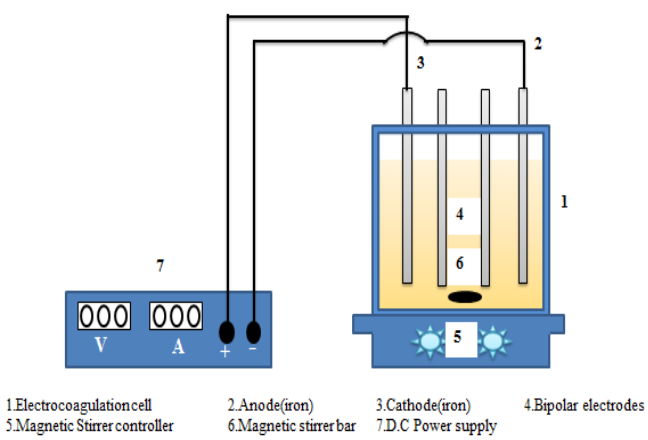

Figure 1) Bench-scale electrocoagulation reactor with bipolar electrodes in parallel connection

Chemical analysis: The dye concentrations were determined by their absorbance characteristics in the UV–visible range (200-800 nm) via the calibration method. The maximum adsorption (λ_{max}) wavelength of dyes was obtained by measuring their absorbance at various wavelengths. All experiments were run at room temperature (22±2ºC).

The calculation of color removal efficiency after EC treatment was performed using following formula:

$$R(\%) = \frac{(C_0 - C)}{C_0} \times 100$$

Where, C_0 is the initial dye concentration (mg/L) and C is the final concentration (mg/L).

Results

In the current study, EC method as a treatment technique by application of iron electrode was used for the removal of RY-14 from textile wastewater; also, some factors, such as effect of initial and final pH, contact time, voltage, energy consumption rate, and initial concentration of dyes were studied. The results are shown in figures 2 to 8.

Figure 2 demonstrates the removal efficiency of RY-14 dye as a function of the influent pH, and when pH of the dye solutions was 2, there was maximum color removal efficiency. According to figure 3, pH increased during the EC.

The effect of KCl concentration on the removal efficiency and the energy consumption is shown in figure 4. According to the results, high color removal percentage with low energy consumption can be obtained in dye solutions with KCl of about 1 g/L.

Figure 5 shows the color removal percentage versus voltages applied to the electrodes in the EC process, and optimum voltage of 40 V was used for the color removal from dye solution; the results showed that an increase in the voltage causes an increase in color removal efficiency. As shown in figure 6, after 25 min of electrolysis, the color removal efficiency reached to maximum at pH 2 and voltage 40 V.

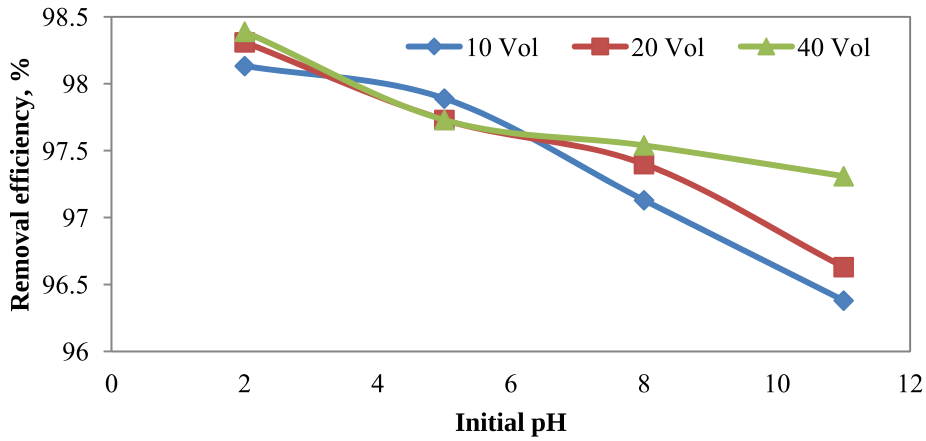

Figure 2) Effect of initial pH on removal efficiency of RY-14 dye (t=15 min, C_0=100 mg/L, d=1 cm, KCl=1 g/L, T=22±2^{0}C, agitation speed=100 rpm)

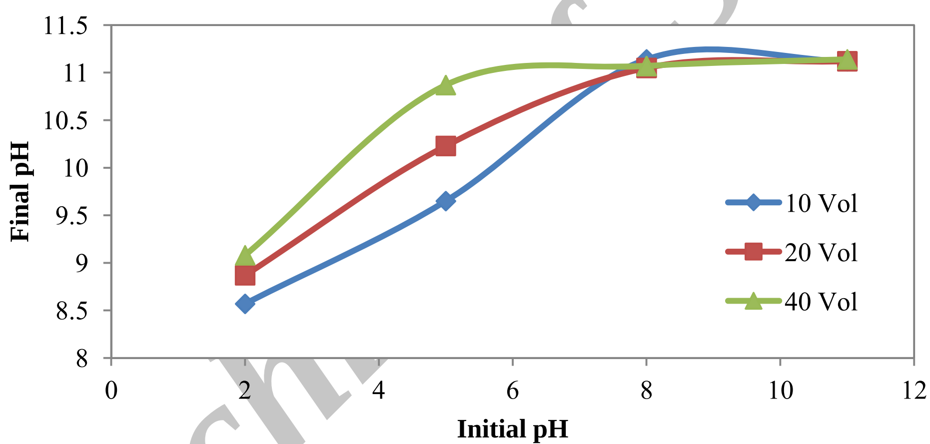

Figure 3) The variation of pH during the EC process (t=15 min, C_0=100 mg/L, d=1 cm, KCl=1 g/L, T=22±2^{0}C, agitation speed=100 rpm)

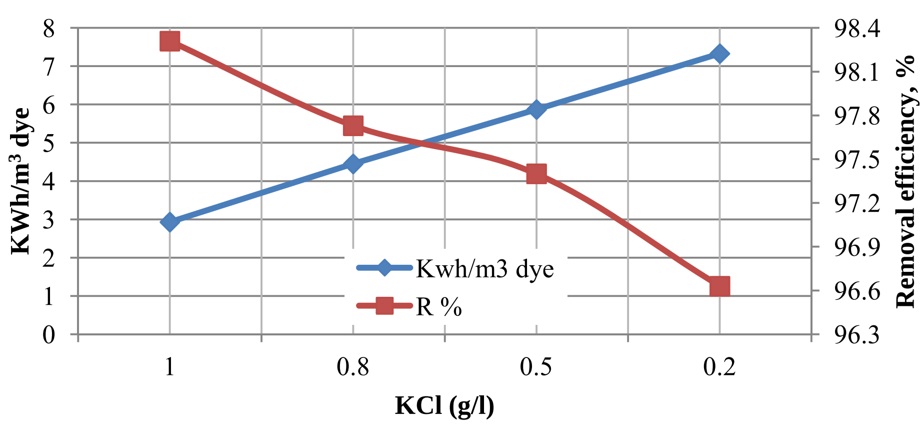

Figure 4) Effect of conductivity on energy consumption and removal efficiency of RY-14 (Vol=20; t=15 min, C_0=100 mg/L, d=1 cm, pH=2, T=22±2^{0}C, agitation speed=100 rpm)

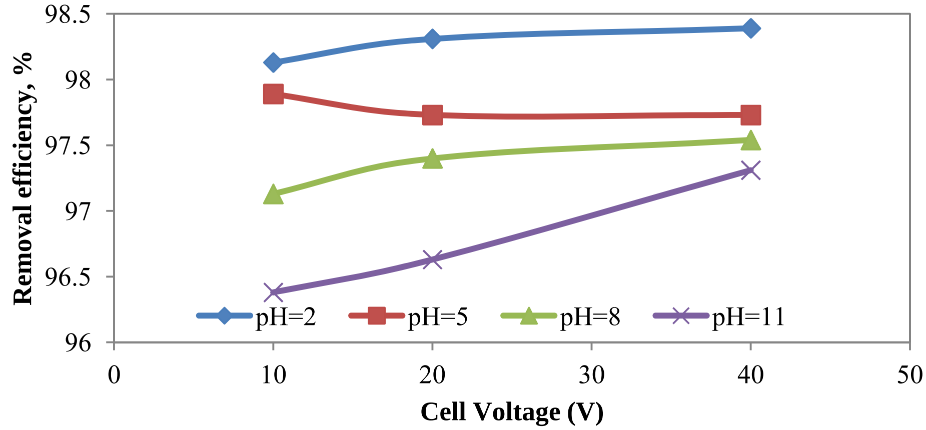

Figure 5) Effect of pH and cell voltage on removal efficiency of RY-14
(t=15 min, C_0=100 mg/L, d=1 cm, pH=2, T=22±2^{0}C, agitation speed=100 rpm)

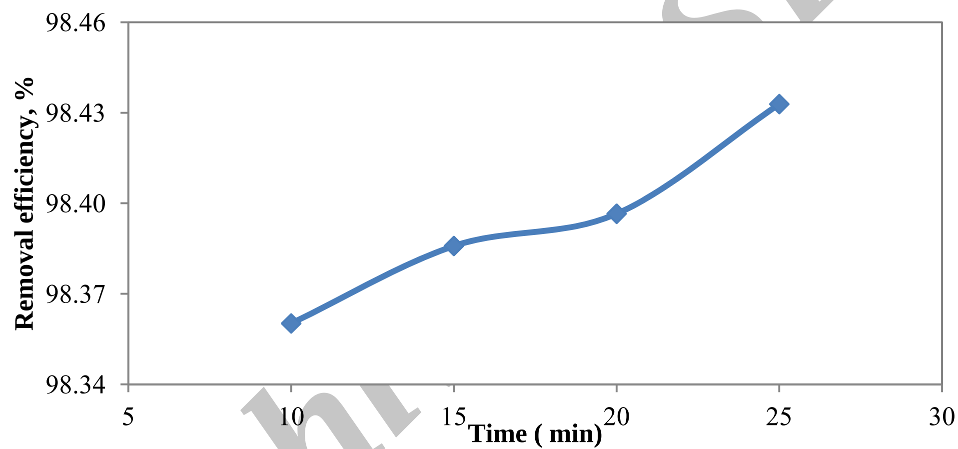

Figure 6) Effect of electrolysis time on the removal efficiency of RY-14
(Vol = 40; KCl = 1 g/L, C_0 =100 mg/L, d=1 cm, T=22±2^{0}C, pH=2, agitation speed=100 rpm)

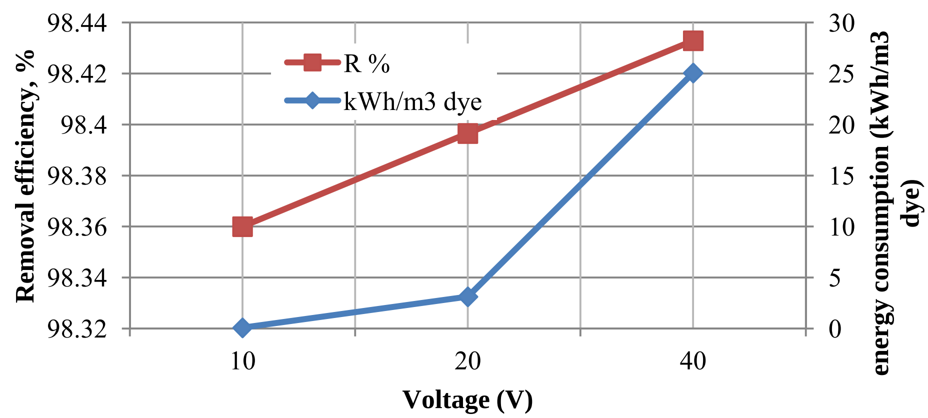

Figure 7) Effect of voltage on energy consumption and the removal efficiency of RY-14
(t= 25 min; KCl=1 g/L, C_0 = 100 mg/L, d = 1 cm, pH=2, T= 22±2^{0}C, agitation speed = 100 rpm)

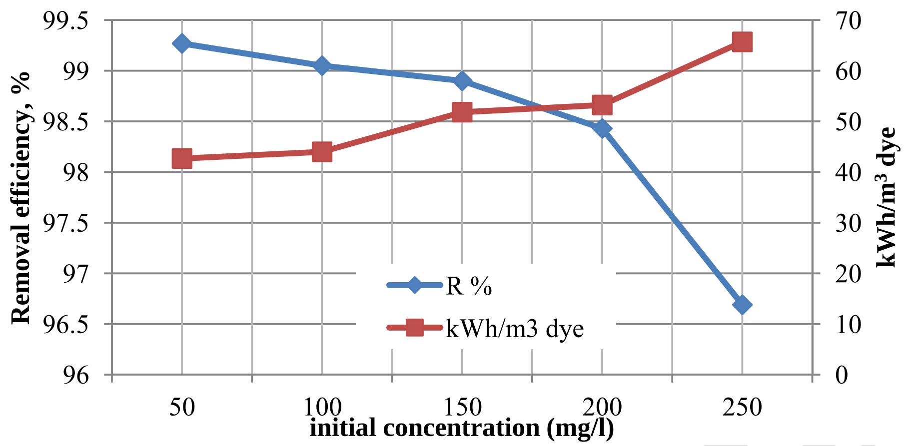

Figure 8) Effect of the initial concentration on the energy consumption and the removal efficiency of RY-14 (t= 25 min; KCl = 1 g/L, Vol= 40v, d = 1cm, pH=2, T= 22±2^{0}C, agitation speed = 100 rpm)

Discussion

pH is a major effective parameter in the performance of the EC process. The kinetics of Fe^{2+} conversion to Fe^{3+} is strongly affected by the pH; the surface charge of the coagulating particle also varies with pH (21). To examine its effect, in each experiment, the sample was adjusted to a distinct pH using sodium hydroxide (NaOH) or sulfuric acid (H_2SO_4). In EC, where Fe electrode is used, it has been observed that $Fe(OH)_3$ precipitation occurs and the sweep-flock mechanism dominates (22).

The results revealed that maximum color removal efficiency were at pH 2. The best removal efficiency in 15 min of electrolysis was 98.39% at pH 2 and voltage 40 V. The mechanism of the electrochemical process in aqueous systems is complex. However, the color removal process may involve the dye molecule adsorbing by both electrostatic and physical attraction. The insoluble metal hydroxides of iron can remove dye molecules by surface complexation or electrostatic attraction. In surface complexation, it is assumed that the dye molecule can act as a ligand to bind a hydrous iron moiety through precipitation and adsorption mechanisms (8,15); pH of the solution was increased during the process. According to former studies done by Merzouk et al. on the removal of disperse red dye from synthetic wastewater in 2011, their results showed that by increasing pH, the dye removal efficiency decreased, and the optimum pH was obtained 5. In another research by Basiri Parsa et al. (2011) on the removal of acid brown 14 in aqueous media, the findings proved that the final solution pH had increased by time (27,28).

Effect of KCl concentration: Potassium chloride (KCl) was used to create conductivity in EC process. Conductivity of solution, cell voltage, and consumption of electrical energy affect the removal efficiency. When the concentration of KCl in solution increases, the conductivity of the solution and the current density also increase. The higher ionic strength will cause an increase in current density at the same cell voltage or equivalently, the cell voltage decreases with increase in the wastewater conductivity at constant current density. Consequently, the necessary voltage to attain a certain current density will diminish and the consumed electrical energy will also decrease (29). According to their results, high color removal percentage with low energy consumption was obtained in dye solutions with KCl of about 1 g/L. The result of Ayhan Sengil's study showed that high color removal percentage with low cell voltages and low energy consumption can be obtained in dye solutions with NaCl of around 3 g/L (29).

Effect of cell voltage: Voltage is the most important parameter for controlling the reaction rate within the reactor. It is obvious that amount of voltage determines the effects on the growth of flocks (23,14). Raising of the voltage causes a significant increase in the oxidation of iron electrodes. Optimum voltage of 40 V was used for all experiment. Daneshvar et al's investigation showed that with increasing the primary voltage in EC process, the removal efficiency also increased (2).

Effect of electrolysis time: The color removal efficiency directly depends on the concentration of hydroxyl and produced metal ions on the electrodes (5). After 25 min of electrolysis, the color removal efficiency reached a maximum of 98.43% at pH 2 and voltage 40 V. Also, previous studies' results were proved this fact that an increase in contact time can enhance dye removal from solution (2,27,28).

Electrical energy consumption: Electrical energy consumption and current efficiency are very important economical parameters in the EC process. Electrical energy consumption was calculated by the following equation (24):

$$E = \frac{UIt_{EC}}{V}$$

Where, E is electrical energy in kWh $(m^3)^{-1}$, U is cell voltage in volt (V), I is current ampere (A), V is the solution volume (m^3) and t_{EC} is the EC process per minute. The value of energy consumption as a function of treated solution volume was also calculated in different voltages for each dye solution.

The results showed that an increase in voltage led to increased removal efficiency. The value of energy consumption as a function of treated solution volume was also calculated in different voltages for each solution pH. Increasing pH from 2 to 11 caused improvement in power requirement during 25 min electrolysis time. The minimum energy consumption was 34.65 KWh/m^3 dye at 40 V, at the 15 minute. The results showed that optimum voltage for energy consumption was 25.6 kWh per m^3 dye.

Two other studies, in accordance with our results, showed that an enhancement in voltage can increase the removal efficiency and consumption energy (2,29).

Effect of the initial concentration: By using iron as sacrificial anode, the removal efficiency of RY-14 dye was significantly reduced to less than 96.69%, when the initial dye concentration increased from 50 to 250 mg/L that is because of the decrease in iron ions in high concentration. In higher concentration, 50 mg/L (99.27%), the adsorption capacity did not reduce and the color removal rate was relatively constant. However, increment of the initial dye concentration caused a steady increase in the decolorization capacity (25).

Conclusion: In this research, the removal efficiency of EC process with iron electrodes and the effect of operating parameters, such as applied voltage, reaction time, initial dye concentration, and interelectrode distance for the treatment of a synthetic solution in batch system has been studied and concluded. The best color removal efficiency for RY-14 was obtained 99.27% at pH 2, initial dye concentration 50 mg L^{-1}, voltage 40 V, KCl concentration 1 g/L, temperature 22±2^{o}C, reaction time 25 min, and electrode distance 1cm. It was concluded that EC process by iron electrode is an efficient and economic method for the removal of reactive dyes from colored solution.

Footnotes

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Conflict of Interest:

The authors declare no conflict of interest.

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