

Effects of Stainless Steel and Iron Electrode on Removal of Dyes in Electrocoagulation Process

Nirav B. Patel, J.P.Ruparelia

Abstract: Electrocoagulation (EC) is one of the most effective techniques to remove color and organic pollutants from wastewater, which reduces the sludge generation. In this paper, electrocoagulation has been used for the removal of color from solutions containing Direct Black 22. The effect of operational parameters such as current density, initial pH of the solution, time of electrolysis, initial dye concentration and solution conductivity were studied in an attempt to reach higher removal efficiency. The findings in this study shows that an increase in the current density up to 0.5 to 1.0 enhanced the color removal efficiency, the electrolysis time was 5, 10 and 15 min and the range of pH was determined between 2.0 to 11.0 for dye solutions. It was found that for, the initial concentration of dye in solutions should not be higher than 100mg/l in order to achieve a high color removal percentage. The optimum conductivity was found to be 4 ms/cm, which was adjusted using proper amount of Nacl with the dye concentration of 50 mg/l. Also, during the EC process under the optimized conditions, the COD decreased by more than 70% and 80% in iron and stainless steel electrode. Color removal efficiency for stainless steel electrode is 99.6% and iron 93.39% respectively.

Keyword – Electrocoagulation; Iron and stainless steel electrodes; Dyes

1. INTRODUCTION

Dyeing and finishing are the two important processes generally applied in most of the textile manufacturing industries. These two processes generate considerable amount of wastewater, which may contain strong color, suspended particles, high pH and high chemical oxygen demand (COD) concentration [1]. It is estimated that 1–15% of the dye is lost during dyeing and finishing processes and is released into wastewaters. The textile industry utilizes about 10,000 dyes and pigments [2]. The disposal of these colored wastewaters poses a major problem for the industry as well as a threat to the environment. As a result, a high amount of these dyes can exist in effluents of dyeing processes. In textile industries, because of the low efficiency (60–90%) of dye fixing on textile fibers, substantial amounts of unfixed dyes are released in wastewaters. Most kinds of synthetic dyes are toxic substances to human and aquatic life [3]. There are

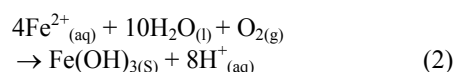
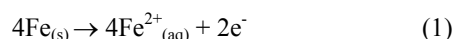
many processes to remove dyes from colored effluents such as adsorption, precipitation, chemical degradation, photodegradation, biodegradation, chemical coagulation and electrocoagulation [4,5]

Treatments of wastewaters containing textile dyes have been studied by electrocoagulation method. The results of these studies show that COD, color, turbidity and dissolved solids at varying operating conditions are considerably removed [6-14]. In addition, it is clear that a technically efficient process must also be economically feasible with regard to its initial capital and operating costs, and practically applicable to the environmental problems. The economic aspect of the electrocoagulation (EC) process is not investigated well by the researches except a few of them [8]. Electrical energy consumption is a very important economical parameter in EC process like all other electrolytic processes.

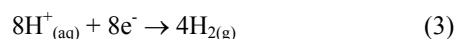
Iron upon oxidation in an electrolytic system produces iron hydroxide, $\text{Fe}(\text{OH})_n$, where $n = 2$ or 3 . Two mechanisms have been proposed for the production of $\text{Fe}(\text{OH})_n$

(a) Mechanism 1:

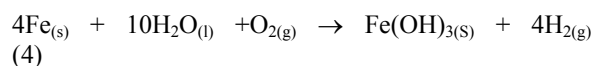
- Anode:



- Cathode:

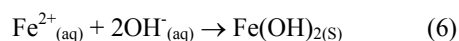
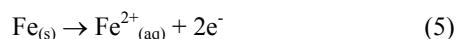


- Overall:

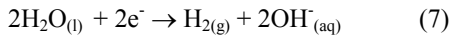


(b) Mechanism 2:

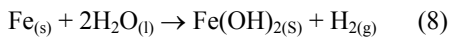
- Anode:



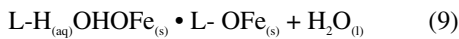
Cathode:



Overall:



The $\text{Fe}(\text{OH})_n(s)$ remains in the aqueous stream as a gelatinous suspension, which can remove the pollutants from the wastewater by either complexation or electrostatic attraction followed by coagulation [15]. In the surface complexation mode, the pollutant acts as a ligand (L) to chemically bind hydrous iron:



2. Experimental

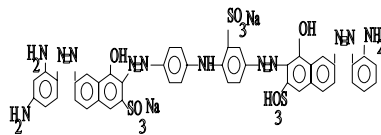
2.1 Materials and methods

The commercial dyes used in this project were purchased from industry. The chemical structure and other characteristics of these dyes are shown in Table 1. Dye solutions were prepared by dissolving dyes in distilled water. The conductivity of solutions was raised up and adjusted in different values by the addition of NaCl. The conductivity measurement was performed using a Philips conductimeter. The pH of the solutions was measured by pH meter and adjusted by adding NaOH or H_2SO_4 solutions. Iron and stainless steel were used as electrode. Dimensions of electrodes were 75mm×65mm×3mm and the distance between two electrodes in EC cell was 8mm in all experiments. The electrodes were connected to a DC power supply with galvanostatic operational options for controlling the current density. All the runs were performed at room temperature. In each run, 500 ml of the dye solution was decanted into the electrolytic cell. At the end of electrocoagulation, all samples were allowed to settle for 20 min in a 500 ml vessel before any analysis. Neither centrifuging nor filtration was performed [16].

Table 2. Experimental Result of Electrocoagulation process

Different electrode	Current density (Amp)	Electrical Potential V	Residence Time (min)	COD removal efficiency (%)	Color removal efficiency (%)			
					pH-2.0	pH-5.0	pH-8.0	pH-11.0
SS	0.5	5.46-5.65	5	19-32.5	74.00	97.74	89.59	26.90
		5.71-5.85	10	19-50	61.55	98.00	90.67	36.10
		5.75-5.85	15	25-62.5	45.31	99.60	92.85	45.31
	1.0	9.71-10.03	5	25-32.5	79.96	99.40	93.39	30.15
		9.68-10.48	10	25-62.5	69.68	99.47	94.48	41.52
		9.68-10.53	15	25-75	46.93	99.67	95.02	50.72
FE	0.5	6.12-6.85	5	19-32.5	61.55	86.33	91.76	48.56
		6.15-6.96	10	19-50	54.51	85.00	91.13	46.39
		6.14-7.05	15	25-62.5	48.02	79.26	90	40.43
	1.0	10.03-10.74	5	25-32.5	68.05	90.67	92.3	50.72
		10.05-10.98	10	25-50	59.93	85.00	80.35	44.22
		10.05-11.21	15	25-62.5	51.81	79.26	91.76	48.56

Table 1. Structure and characteristic of Direct Black 22

Dye	Direct Black 22
Structure	
λ_{max} (nm)	482
Chemical class	Tetraazo
Mw	565

2.2. Chemical Analysis

The dyes concentrations were determined from their absorbance characteristics in the UV- vis range (200-800 nm) with the calibration method.

A WPA lightwave spectrophotometer connected to a PC was used. For this measurement, the maximum adsorption (λ_{max}) wavelength of dyes was determined by measuring their absorbance at various wavelength. The calculation of color removal efficiency after electrocoagulation treatment was performed using this formula:

$$\text{CR} (\%) = (\text{Co}-\text{C})/\text{Co} * 100$$

where C_0 and C are concentrations of dye before and after electrocoagulation in mg/l respectively.

The chemical oxygen demand (COD) of dye solutions was measured according to the standard methods for examining water and wastewater [14].

3. Result and Discussion

The focus of this work is to assess the feasibility of electrocoagulation to degradation of dyes from solution. An effort was made to understand the phenomenon of degradation of dyes by performing various experiments. Also experiment was carried out with different electrodes, at different current density, at different pH, at different residence time.

3.1 Effect of Initial pH

It has been established that pH is an important operating factor influencing the performance of electrocoagulation process. Generally, the pH of the medium changes during the process, as observed also by other investigators. This change depends on the type of electrode material and on initial pH. In the case of stainless steel, the final pH is higher for initial pH < 8, and above this point the final pH is lower.

Furthermore, for iron, the final pH is always higher than initial pH. The difference between initial and final pH values diminishes for initial pH > 8 [9]. These results suggest that electrocoagulation exhibits some pH buffering capacity, especially in an alkaline medium. The effect of initial pH on the COD and color removal efficiencies is presented in Fig 1 & 2 for the stainless steel electrode. As seen, for pH < 6, the color removal efficiency is as high as 99.6% and 75% for COD removal. Color removal efficiency and COD removals drop dramatically at pH > 6. On the other hand, for iron electrodes, in the range 6-9 initial pH, the color removal efficiency and COD removals reach 95% and 70% respectively. There was minimum removal efficiency at the pH ≤ 2. Since hydroxide ions, which were generated at the cathode, were neutralized by H⁺ ions, sufficient amount of iron hydroxide complexes were not formed at this pH. At the pH ≥ 9, color removal efficiency decreased as much as about 9%, because above this pH Fe(OH)₄⁻ is the dominant species. Fe(OH)₄⁻ is a dissolving species and it is unable to form flocs [17].

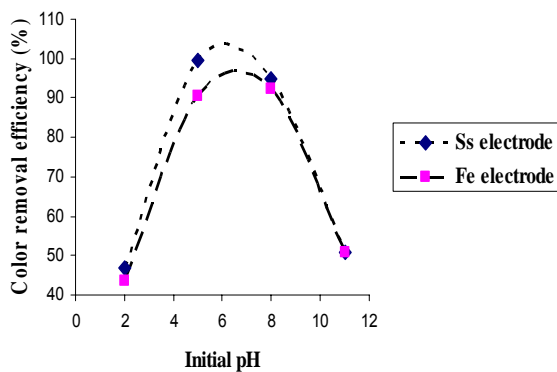


Fig 1: Effect of Initial pH on color removal efficiency (Co-100mg/L, γ-4-12ms/cm, t_{BC}-15 min)

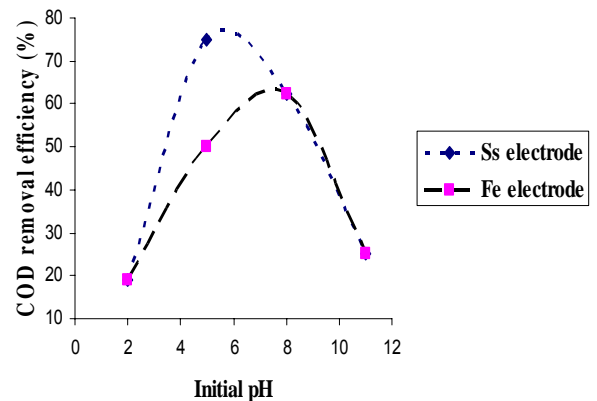


Fig 2: Effect of Initial pH on COD removal efficiency (Co-100mg/L, γ-4-12ms/cm, t_{BC}-15 min)

3.2 Effect of Time of electrolysis

Reactive time also influences the treatment efficiency of the electrochemical process. Electrolysis time (t) determines the production rate of Fe²⁺ or Fe³⁺ ions from iron electrodes. Fig. 3 shows the relationship between the color removal efficiency and the electrolysis time. In Ss electrode, increase the time of electrolysis from 5 to 15 min corresponding to increase the color and COD removal efficiency up to 99.67% and 75% respectively. In Fe electrode, increase the time of electrolysis from 5 to 15 min corresponding to increase color and COD removal efficiency up to 92.3% and 62.5% respectively [16]

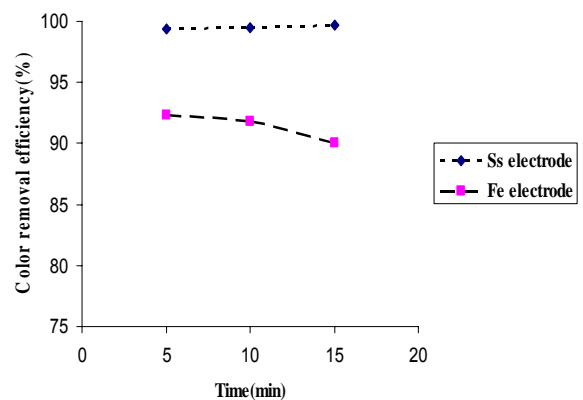


Fig 3: Effect of Time of electrolysis on color removal efficiency (Co-100 mg/L, γ-4-12ms/cm, pH-5.0 (ss) & 8.0 (Fe))

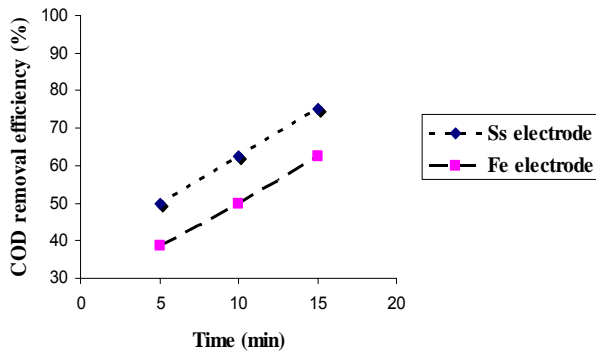


Fig 4: Effect of Time of electrolysis on COD removal efficiency (Co-100 mg/L, γ -4-12ms/cm, pH-5.0 (ss) & 8.0 (Fe))

The color removal efficiency depends directly on the concentration of hydroxyl and metal ions produced on the electrodes.

3.3 Effect of Current density

In all electrochemical processes, current density is the most important parameter for controlling the reaction rate within the reactor. It is well known that the amount of current density determines the coagulant production rate, and adjusts the rate and size of the bubble production, and hence affects the growth of flocs. To investigate the effect of current density on the efficiency of color removal, electrocoagulation process was carried out using various current densities [18].

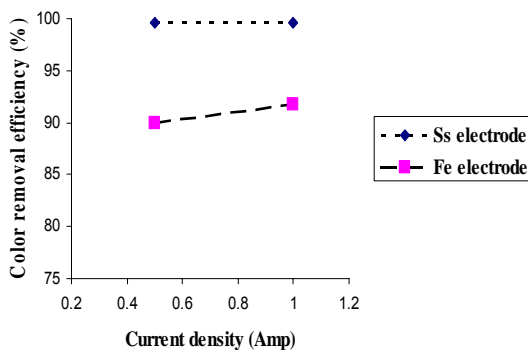


Fig 5: Effect of Current density on Color removal efficiency (Co-100 mg/L, γ -4-12ms/cm, pH-5.0(ss) & 8.0(Fe))

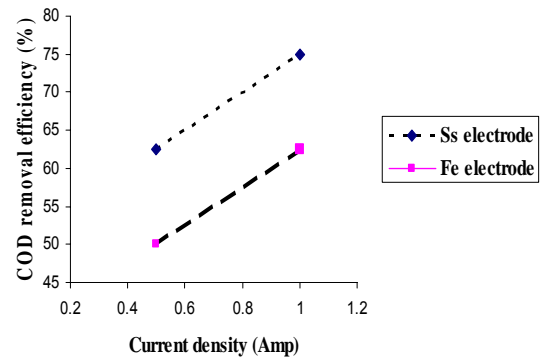


Fig 6: Effect of Current density on COD removal efficiency (Co-100mg/L, γ -4-12ms/cm, pH-5.0(ss) & 8.0 (Fe))

Fig. 5 shows the color removal percentage against current density applied to the electrodes in the EC process. Raising current density causes a corresponding increase in the oxidized iron production from electrodes. The optimum current density of 1.0 Amp was used for the color removal from dye solution containing both Ss and Fe electrode.

Conclusion

The use of iron and stainless steel as a sacrificial electrode material in the treatment of degradation of dyes by electrocoagulation has been found to be pH dependent. According to the results, In acidic medium, pH<6, COD and Color removal efficiencies of stainless steel are higher than those of iron, while neutral and alkaline medium iron is preferable.

References

1. Y.A. Mohammad, R. Saurabh, K. Prashanth, V. Madhavi, S. Tejas, A.G. Jewel, K. Mehmet, L. David, Treatment of orange II azo-dye by electrocoagulation (EC) technique in a continuous flow cell using sacrificial iron electrodes, *J. Hazard. Mater. B* 109 (2004) 165–171.
2. N. Daneshvar, M. Rabbani, N. Modirshahla, M.A. Behnajady, Photooxidative degradation of Acid Red 27 in a tubular continuous-flow photoreactor: influence of operational parameters and mineralization products, *J. Hazard. Mater. B* 118 (2005) 155–160.
3. M.N. Pons, A. Alinsafi, M. Khemis, J.P. Leclerc, A. Yaacoubi, A. Benhammou, A. Nejmeddine, Electrocoagulation of reactive textile dyes and textile wastewater, *Chem. Eng. Process.* 44 (2005) 461–470.

4. Y.M. Slokar, A.M.L. Marechal, Methods of decoloration of textile wastewaters, *Dyes Pigments* 37 (1998) 335–356.
5. N. Daneshvar, D. Salari, S. Aber, Chromium adsorption and Cr(VI) reduction to trivalent chromium in aqueous solutions by soya cake, *J. Hazard Mater. B* 94 (2002) 49–61.
6. M.N. Pons, A. Alinsafi, M. Khemis, J.P. Leclerc, A. Yaacoubi, A. Benhammou, A. Nejmeddine, Electrocoagulation of reactive textile dyes and textile wastewater, *Chem. Eng. Process.* 44 (2005) 461–470.
7. Y.M. Slokar, A.M.L. Marechal, Methods of decoloration of textile wastewaters, *Dyes Pigments* 37 (1998) 335–356.
8. M. Kobya, O.T. Can, M. Bayramoglu, M. Sozbir, Operating cost analysis of electrocoagulation of textile dye wastewater, *Sep. Purif. Technol.* 37 (2004) 117–125.
9. M. Kobya, O.T. Can, M. Bayramoglu, Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes, *J. Hazard. Mater. B* 100 (2003) 163–178.
10. M.Y.A. Mollah, S.R. Pathak, P.K. Patil, M. Vayuvegula, T.S. Agrawal, J.A.G. Gomes, M. Kesmez, D.L. Cocke, Treatment of orange II azo-dye by electrocoagulation (EC) technique in a continuous flowcell using sacrificial iron electrodes, *J. Hazard. Mater. B* 109 (2004) 165–171.
11. T. Kim, C. Park, E. Shin, S. Kim, Decolorization of disperse and reactive dyes by continuous electrocoagulation process, *Desalination* 150 (2002) 165–175.
12. M. Kobya, O.T. Can, M. Bayramoglu, Decolorization of reactive dye solutions by electrocoagulation using aluminum electrodes, *Ind. Eng. Chem. Res.* 42 (2003) 3391–3396.
13. N. Daneshvar, H. Ashassi-Sorkhabi, A. Tizpar, Decolorization of orange II by electrocoagulation method, *Sep. Purif. Technol.* 31 (2003) 153–162.
14. N. Daneshvar, H. Ashassi-Sorkhabi, M.B. Kasiri, Decolorization of dye solution containing Acid Red 14 by electrocoagulation with a comparative investigation of different electrode connections, *J. Hazard. Mater. B* 112 (2004) 55–62.
15. M. Yousuf A. Mollah, Robert Schennach, Jose R. Parga2, David L. Cocke, Electrocoagulation (EC)—science and applications, *J. Hazard. Mater. B* 84 (2001) 29–41.
16. N. Daneshvar, A. Oladegaragoze, N. Djafarzadeh, Decolorization of basic dye solutions by electrocoagulation: An investigation of the effect of operational parameters, *J. Hazard. Mater. B* 129 (2006) 116–122.
17. N. Daneshvar, A.R. Khataee, A.R. Amani Ghadim, M.H. Rasoulifard, Decolorization of C.I. Acid Yellow 23 solution by electrocoagulation process: Investigation of operational parameters and evaluation of specific electrical energy consumption (SEEC), *J. Hazard. Mater.* 148 (2007) 566–572.
18. N. Daneshvar, A.R. Khataee, N. Djafarzadeh, The use of artificial neural networks (ANN) for modeling of decolorization of textile dye solution containing C. I. Basic Yellow 28 by electrocoagulation process, *J. Hazard. Mater. B* 137 (2006) 1788–1795.