

## Basic and Applied Aspects in the Electrochemical Degradation of Color Removal in the Industrial Effluent

K. Rathinakumaran\*, Rm. Meyyappan

*Electrochemical Engineering Lab, Department of Chemical Engineering, Annamalai University, Annamalai Nagar – 608 002, TN, India.*

### ARTICLE DETAILS

#### Article history:

Received 25 July 2015

Accepted 06 August 2015

Available online 07 August 2015

#### Keywords:

Electrochemical Oxidation

Decolorisation

Rotating Cathode

Wastewater Treatment

Mixed Oxide Anode

### ABSTRACT

This study deals with the treatment of dye wastewaters from textile industries by electrochemical oxidation using Ti/RuO<sub>2</sub>-IrO<sub>2</sub> anode and rotating stainless steel cathode in a batch reactor. The main objective of the present work is to reduce the color of the dye effluent. The influence of various experimental parameters such as initial pH, initial dye concentration, cathode rotation speed, current density, electrolyte concentration, reaction temperature were calculated and presented. From the results, electrochemical oxidation process complete color removal was achieved at optimum conditions.

## 1. Introduction

Wastewater discharged from industries contains contaminants including dyes. Nowadays the public has become more sensitive towards the protection of environment and its awareness. Various treatment methods have been reviewed in the removal of color. Textile industries use large quantities of chemicals and dyes, which are wasted in the effluents, pollute the ground and surface water bodies [1, 2]. The inefficiencies in the dyeing process result in dyestuff losses between 2-50% [3]. Various physio-chemical, biological and electrochemical methods exist for the treatment of effluents. A number of biological processes, such as sequenced anaerobic/aerobic digestion, have been proposed in the treatment of textile wastewater [4, 5]. But they are limited because many of the dyes are xenobiotic and non-biodegradable. Of all the conventional processes the electrochemical methods play an important role in the different textile processes for color removal in the industrial waste water. [6-11]. Due to the variation of wastewater characteristics, such as temperature, pH and heavy COD load the combined physical, biological and chemical method treatment systems become inefficient [12]. On the other hand, electrochemical oxidation is becoming an alternative wastewater treatment method for toxic wastewaters, which are not easily biodegradable and requiring costly physical or physicochemical pretreatments [13]. The electrochemical process effectiveness depends upon the nature of the anode selected, stable anodes that are prepared by the deposition of a thin layer of metal oxides on a base metal. Many researchers have investigated electrochemical oxidation for azo dye degradation through operating parameters optimization using various anodes including RuO<sub>2</sub> [14], SnO<sub>2</sub> [15], PbO<sub>2</sub> [16] and diamond electrode [17]. In this work, the textile effluent was subjected to electrochemical treatment using Ti/RuO<sub>2</sub>-IrO<sub>2</sub> anode and rotating stainless steel cathode in a batch reactor. The effect of initial pH, initial dye concentration, cathode rotation speed, current density, electrolyte concentration, reaction temperature, in the efficiency of the process was studied and the optimum condition for complete Color removal was established.

## 2. Experimental Methods

### 2.1 Textile Dye Wastewater

The textile dye wastewater was collected from a private small-scale industry located at Cuddalore, Tamilnadu, India. The wastewater was analyzed and various parameters as given in Table 1. The wastewater was stored below 5 °C in airtight plastic containers. The chemicals used for the experiments and the analysis techniques were AR grade unless otherwise mentioned.

**Table 1** Chemical characteristics of textile dye effluent

| S. No. | Parameters             | Values        |
|--------|------------------------|---------------|
| 1      | COD                    | 3500 mg/L     |
| 2      | Conductivity           | 16.42 mmho/cm |
| 3      | pH                     | 9.0           |
| 4      | Color                  | Purple Blue   |
| 5      | Chloride content       | 42943 mg/L    |
| 6      | Total Dissolved solids | 48000 mg/L    |
| 7      | Suspended Solids       | 2100 mg/L     |

### 2.2 Experimental Setup

The electrochemical reactor used in the present study was made of Pyrex glass of 1000 mL capacity with a provision to fit a cathode and an anode (surface area of the electrode 38.46 cm<sup>2</sup>). The disc shaped titanium based mixed oxide anode Ti/RuO<sub>2</sub>-IrO<sub>2</sub> as anode and rotating stainless steel as cathode were arranged horizontally and parallel to each other with 1cm inter-electrode gap. A DC power supply, used as a source for electric power for the experiments, with ammeter and voltmeter. The experimental setup was shown in Fig. 1.

\*Corresponding Author

Email Address: [krkumaran@rediffmail.com](mailto:krkumaran@rediffmail.com) (K. Rathinakumaran)

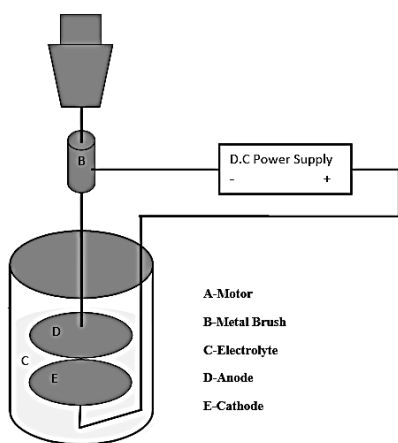


Fig. 1 Electrochemical reactor with rotating disc electrode

### 2.3 Experimental Procedure

Batch experiments were adopted in the present study in order to facilitate identification of the optimum operating conditions of the treatment process. At the beginning of each test run, 500 mL of synthetic dye effluent was loaded in the electrochemical reactor; specific current at pre-determined interval of time was applied using a regulated power supply. Experimental factors namely initial pH, initial concentration, cathode rotation speed, current density, electrolyte concentration, reaction temperature were varied with development of experiment. At the pre-determined time interval, 5 mL of sample was collected and reduction of Color was determined to know the extent of degradation of effluent.

### 2.4 Analysis - Color Removal

Dye concentration was analyzed spectrophotometrically by measuring the absorbance of remaining dye at maximum wavelength 625 nm on UV-Vis spectrophotometer (Elico, SL 164, Hyderabad, India).

From the absorbance values the reduction in the color removal was calculated by following formula

$$\% \text{Color Removal} = 100 \times \frac{[ABS_0^M - ABS^M]}{ABS_0^M} \quad (1)$$

Where,  $ABS^M$  – the absorbance value at its maximum absorbency visible wavelength.

$ABS_0^M$  – the value before treatment

$ABS^M$  – the value after treatment.

## 3. Results and Discussion

### 3.1 Effect of Current Density

The current density was varied 25 mA/cm<sup>2</sup>, 50 mA/cm<sup>2</sup>, 75 mA/cm<sup>2</sup>, 100 mA/cm<sup>2</sup> and 125 mA/cm<sup>2</sup> to enumerate the effect of current density on effective removal of color. The effect of current density in color removal was shown Fig. 2. Increase in current density increases the percentage color removal. The complete color removal was achieved at 55, 45, 30, 24 and 20 minutes for current density of 25 mA/cm<sup>2</sup>, 50 mA/cm<sup>2</sup>, 75 mA/cm<sup>2</sup>, 100 mA/cm<sup>2</sup> and 125 mA/cm<sup>2</sup> respectively.

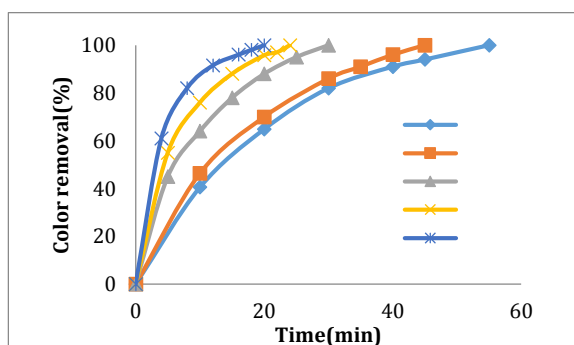


Fig. 2 Effect of current density on color removal [A-25 mA/cm<sup>2</sup>, B-50 mA/cm<sup>2</sup>, C-75 mA/cm<sup>2</sup>, D-100 mA/cm<sup>2</sup>, E-125 mA/cm<sup>2</sup>]; [Initial pH = 6; Cathode rotation speed = 750 RPM; Initial dye concentration = 20%; Electrolyte concentration = 4 g/L; Temperature = 25 °C]

### 3.2 Effect of Temperature

The effect of temperature was studied by varying the temperature 20 °C, 25 °C, 30 °C, 35 °C and 40 °C. The effect of temperature in color removal was shown Fig. 3. Increase in temperature increase the rate of color significantly until 25 °C further increase in temperature decrease the rate of removal this was due to chemical decomposition of sodium hypochlorite to sodium chlorate. Therefore, when temperature rises, production of NaClO falls and the degradation also decreases. The optimum condition for the process was 25 °C where complete color removal was achieved at 24 minutes.

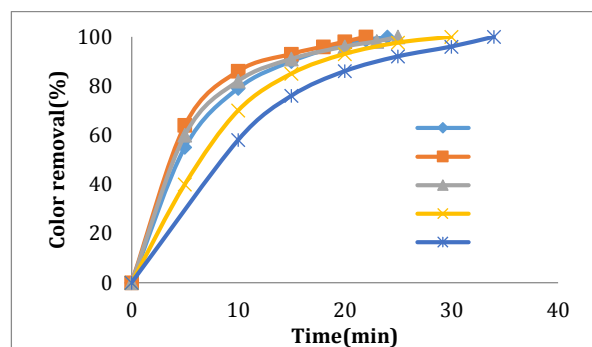


Fig. 3 Effect of temperature on color removal [A-20 °C, B-25 °C, C-30 °C, D-35 °C, E-40 °C]; [Initial pH = 6; Cathode rotation speed = 750 RPM; Initial dye concentration = 20%; Electrolyte concentration = 4 g/L; current density = 100 mA/cm<sup>2</sup>]

### 3.3 Effect of Cathode Rotation Speed

The effect of RPM (rotation per minute) of cathode was studied by varying the RPM, 250, 500, 750, 1000 and 1250. The effect of cathode rotation speed in color removal was shown Fig. 4. The reduction rate increases with increasing cathode rotation speed this may be due to adequate high mass transfer. Increase in rpm decrease the time for color removal until 750 rpm where complete color removal was achieved at 24 minutes. Further increase in cathode rotation speed beyond optimum favors the cathodic reduction of generated hypochlorite thereby decrease the removal of color.

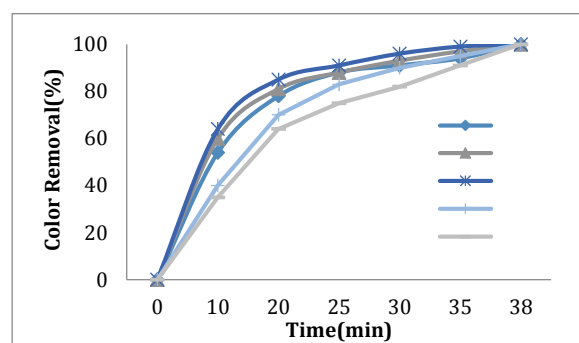


Fig. 4 Effect of Cathode Rotation Speed [RPM] on color removal [A-250, B-500, C-750, D-1000, E-1250]; [Initial pH = 6; Temperature = 25 °C; Initial dye concentration = 20%; Electrolyte concentration = 4 g/L; current density = 100 mA/cm<sup>2</sup>]

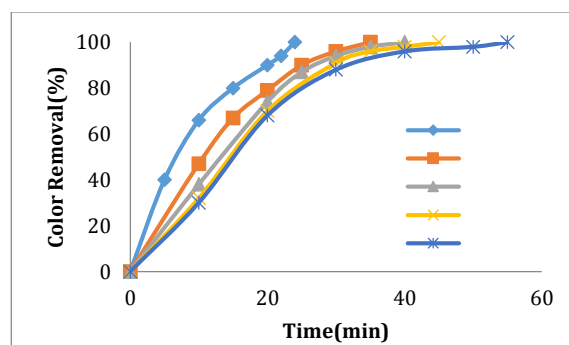


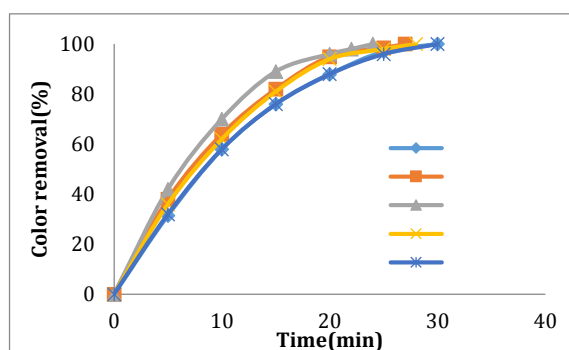
Fig. 5 Effect of Initial Concentration on color removal [A-20%, B-40%, C-60%, D-80%, E-100%]; [Initial pH = 6; Temperature = 25 °C; Cathode rotation speed = 750 RPM; Electrolyte concentration = 4 g/L; current density = 100 mA/cm<sup>2</sup>]

### 3.4 Effect of Initial Concentration

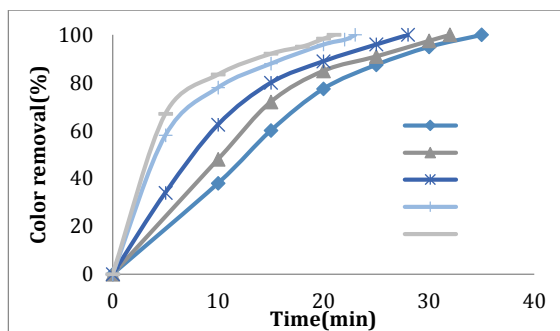
The effect of initial concentration of dye effluent was studied by varying the dilution 20, 40, 60, 80 and 100 %. The effect of initial concentration in color removal was shown Fig. 5. The percentage color removal rate was reduced with increase in the dye concentration. As the initial concentration increase, the degradation efficiency decrease. This shows that the generation of the powerful oxidizing agent  $\text{Cl}^-$  ions on electrode surface was not increased in constant current density. The optimum condition selected was 20% where complete color removal was achieved at 8 minutes.

### 3.5 Effect of pH

The effect of pH of dye was studied by varying the pH 2, 4, 6, 8 and 10. The pH of the dye solutions was adjusted to desired values with 0.1 mol/L HCl or 0.1 mol/L NaOH. The effect of pH in color removal was shown Fig. 6. Varying the initial pH between 2 and 10 does not have significant influence on the color removal. Many investigators explained the fact that the generation of chlorine/hypochlorite is not depending on the initial pH conditions. The generation of chlorine is more or less same under the fixed current density, irrespective of the initial pH values. At 6 pH complete color removal was achieved at 24 minutes.



**Fig. 6** Effect of pH on color removal [A-2, B-4, C-6, D-8, E-10] [Initial dye concentration = 20%; Electrolyte concentration = 4 g/L; Temperature = 25 °C; Cathode rotation speed = 750 RPM; current density = 100 mA/cm<sup>2</sup>]



**Fig. 7** Effect of Electrolyte Concentration on color removal [A-1 mg/L, B-2 mg/L, C-3 mg/L, D-4 mg/L, E-5 mg/L]; [Initial dye concentration = 20%; Temperature = 25 °C; Cathode rotation speed = 750 RPM; pH = 6; current density = 100 mA/cm<sup>2</sup>]

### 3.6 Effect of Electrolyte Concentration

The effect of electrolyte concentration was studied by varying the concentration 1, 2, 3, 4 and 5 g/L of NaCl. The effect of electrolyte in color removal was shown Fig. 7. An increase of the electrolyte concentration up to 4 g/L leads to increase in the color removal. The NaCl solution liberates  $\text{Cl}_2$  gas, which is consider as the active species for the degradation of

organic compound. Further increase of the NaCl concentration has slightly effect on the color and COD removal. The optimum condition was 4 g/L where complete color removal was achieved at 23 minutes.

## 4. Conclusion

Electrochemical oxidation of industrial effluent was achieved efficiently in medium containing NaCl using Ti/RuO<sub>2</sub>-IrO<sub>2</sub> anode and rotating cathode in an electrochemical reactor. The color removal depends on current intensity, initial concentration of the dye, pH, temperature and cathode rotation speed. The increase in current density increases the color removal. Temperature has no significance in the removal of color, increase in temperature shows very low increase in removal where the energy requirement for heating the effluent will go high, increasing the process cost. Maximum removal was obtained at 6 pH. Increase in mass transport increases the percentage removal color, which was achieved by increasing the cathode rotation speed. The best conditions for the color removal were found to be 100 mA/cm<sup>2</sup>, 20%, pH 6, 25 °C, 4 g/L NaCl and 750 rpm. According to these results, the electrochemical method could be a strong alternative to conventional physicochemical methods for the treatment of industrial textile wastewater with further research.

## References

- [1] A.B. Dos Santos, F.J. Cervantes, J.B.V. Lier, Review paper on current technologies for decolourisation of textile wastewater perspectives for anaerobic biotechnology, *Bioresour. Technol.* 98 (2007) 2369-2385.
- [2] D. Wesenberg, I. Kyriakides, S.N. Agathos, White- rot fungi and their enzymes for the treatment of industrial dye effluents, *Biotechnol. Adv.* 22 (2003) 161-187.
- [3] T. Robinson, G. McMullan, R. Marchant, P. Nigam, Remediation of dyes in textile effluent a critical review on current treatment technologies with a proposed Alternative, *Bioresour. Technol.* 77 (2001) 247-255.
- [4] Y. Fu, T. Viraragavan, Fungal decolorisation of dye wastewaters review *Bioresour. Technol.* 79 (2001) 251.
- [5] A. Stolz, Basic and applied aspects in the microbial degradation of azo dyes, *Appl. Microbiol. Biotechnol.* 56 (2001) 69-80.
- [6] P.A. Carneiro, M.E. Osugi, C.S. Fugivara, N. Boralle, M. Furlan, M.V.B. Zanoni, Evaluation of different electrochemical methods on the oxidation and degradation of Reactive Blue 4 in aqueous solution, *Chemosphere* 59(3) (2005) 431-439.
- [7] S.H. Lin, C.F. Peng, Treatment of textile wastewater by electrochemical method, *Water. Res.* 28(2) (1994) 277-282.
- [8] S.H. Lin, C.F. Peng, Continuous treatment of textile wastewater by combined coagulation, electrochemical oxidation and activated sludge, *Water. Res.* 30 (1996) 587-592.
- [9] M.V.B. Zanoni, A.G. Fogg, J. Barek, J. Zima, Electrochemical investigations of reactive dyes; cathodic stripping voltammetric determination of anthraquinone-based chlorotriazine dyes at a hanging mercury drop electrode, *Anal. Chim. Acta* 349(1-3) (1997) 101-109.
- [10] S.H. Lin, M.L. Chen Textile wastewater treatment by enhanced electrochemical method and ion exchange, *Environ. Technol.* 18 (1997) 739-746.
- [11] A.G. Vlyssides, M. Loizidou, P.K. Karlis, A.A. Zorpas, D. Papaioannou, Electrochemical oxidation of a textile dye wastewater using a Pt/Ti electrode, *J. Hazard. Mater.* 70 (1999) 41-52.
- [12] A.G. Vlyssides, D. Papaioannou, M. Loizidou, P.K. Karlis, A.A. Zorpas, Testing an electrochemical method for treatment of textile dye, *Waste Manage.* 20 (2000) 569-574.
- [13] C. Pulgarin, N. Adler, P. Peringer, Ch. Comninellis, Electrochemical detoxification of a 1,4-benzoquinone solution in wastewater treatment, *Water. Res.* 28 (1994) 887-893.
- [14] N. Mohan, N. Balasubramanian, V. Subramanian, Electrochemical Treatment of Simulated Textile Effluent, *Chem. Eng. Technol.* 24(7) (2001) 749-753.
- [15] N. Mohan, N. Balasubramanian, V. Subramanian, In situ electrocatalytic oxidation of acid violet dye effluent, *J. Hazard. Mater.* 136 (2006) 239-243.
- [16] H.S. Awad, N.A. Galwa, Electrochemical degradation of acid blue and basic brown dyes on Pb/PbO<sub>2</sub> electrode in the presence of different conductive electrolyte and effect of various operating factors, *Chemosphere* 61(9) (2005) 1327-1335.
- [17] X.M. Chen, G.H. Chen, PL. Yue, Anodic oxidation of dyes at novel Ti/B-diamond electrodes, *Chem. Eng. Sci.* 58(3-6) (2003) 995-1001.