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# Treatment of Colored Wastewater from Textile Industry Using Electrocoagulation Process

# معالجة مياة الصرف الملونة الناتجة من صناعة النسيج بإستخدام الترويب الكهربي

Mahmoud Khedher, Mohamed Mossad and Hisham Kh. El-Etriby

**KEYWORDS:**
*Electrocoagulation,*
*Initial concentration,*
*Energy consumption,*
*Voltage,*
*Removal efficiency*

*الملخص العربي:-* عملية الترويب الكهربي واحده من الطرق الفعالة فى مجال معالجة مياة الصرف الناتجة من صناعة النسيج حيث انها تمتاز بكونها تكنولوجيا بسيطة واقتصادية و تنتج كمية أقل من الرواسب مقارنة بالطرق التقليدية للمعالجة. تم دراسة اداء عملية الترويب الكهربي فى ازالة اللون لمحلول من العينات التي تم تحضيرها فى المعمل بتركيزات مختلفة من الصبغة باستخدام الواح من الحديد. تم دراسة تأثير عوامل التشغيل المختلفة مثل الجهد الكهربي ، درجة الحامضية للمحلول و مدة التشغيل للتجربة علي كفاءة إزلة اللون و استهلاك الطاقة وذلك لتحديد عوامل التشغيل المثلي للنظام. تبين من النتائج ان كفاءة الإزالة للون يحدث لها ثبات بعد مرور من 20 الى 25 دقيقة من التشغيل وذلك عند استخدام جهد كهربي من 10 الي 20 فولت. كما تبين انه تم ازالة اللون بكفاءة عاليه واستهلاك اقل للطاقة فى حالة استخدام محلول يحتوي علي صبغة بتركيز 250 ملجم/لتر عند استخدام جهد كهربي 10 فولت و درجة حامضية للمحلول تتراوح ما بين 6 الى 9 . و تبين ان كفاءة إزالة اللون ترتبط بصورة عكسية مع تركيز الصبغة للمحلول فى بداية التجربة علي الرغم من ان كفاءة استهلاك الطاقة تزداد فى حاله زيادة التركيز الداخل.

*Abstract*— **Electrocoagulation (EC) is one of the attractive methods for textile wastewater treatment because it is simple, economic and less sludge production technology. The performance of a batch EC process was studied for decolorization of synthetic colored water containing different concentrations of dye using iron electrodes. The effect of various operational conditions such as applied voltage, initial pH and processing time on color removal efficiency and energy consumption was studied in order to identify the optimum operational conditions. It was noticed that the removal efficiency of dye stabilized after 20 to 25 min. of operation using applied voltage between 10 to 20 V. The results indicate that the dye was removed with high efficiency using applied voltage of 10 V and initial pH ranged from 6 to 9 for a solution with initial dye concentration of 250 mg/l. Color removal efficiency is inversely related to solution initial dye concentration. However, the energy consumption efficiency is directly related to solution initial dye concentration.**

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*Mahmoud Khedher, Demonstrator, Public Works Dept., Faculty of Engineering, Mansoura University, Egypt,(email: mmkhedher@gmail.com )*

*Mohamed Mossad, Lecturer, Public Works Dept., Faculty of Engineering, Mansoura University, Egypt,( email: mohamed_a_hakiem@hotmail.com )*

*Hisham Kh. El-Etriby Associate Professor, Public Works Dept., Faculty of Engineering, Mansoura University, Egypt, (email: eletribyhk@yahoo.com )*

## I. INTRODUCTION

Water scarcity is one of the most critical problem that facing humanity because of population explosion so that the protection of water resources against pollution has become an absolute necessity. Many industries consume large amount of clean water especially that are using dyes such as textile, paper, leather, and plastic industries that discharge its hazardous wastewater into water resources or wastewater network without proper treatment which causes a serious problem to the environment and human health, so it is a must to treat and/or reuse this industrial wastewater.

Textile industry consumes large amounts of clean water and different chemicals at various processing stages, in addition, its wastewater is characterized by strong color, high chemical oxygen demand, high total dissolved solids concentration, high temperature, high variation in pH and low biodegradability. The direct discharge of this wastewater into water bodies affects the aquatic life and human health negatively, also discharging it into sewage network causes problems in the biological treatment systems [1]. The major component of the textile wastewater is dyes. There are different types of dyes used in textile industry such as reactive, vat, direct, dispersive, basic, acid, and azo dyes, but the most used are reactive dyes because of its good characteristics [2, 3].

There are many conventional methods used for textile wastewater decolorization such as chemical coagulation, precipitation, adsorption, chemical degradation, photodegradation, and biodegradation. Although Biodegradation method is cheaper than other methods, it has low efficiency because of the dyes toxicity that affects the development of microorganisms inversely [4]. Chemical coagulation is suitable for Sulphur and dispersive dyes, but other types of dyes do not settle after coagulation. Adsorption of dye molecules is an efficient method, on the other hand it consumes a long time and adsorbent regeneration is expensive. In spite of chemical degradation by oxidants such as chlorine and ozone are effective method, it is not preferred because of its toxic byproducts [5].

In recent years, one of the promising technologies that attracted researchers is electrocoagulation (EC) technology has many advantages because of its simplicity and efficiency for the treatment of various wastewater. Electrocoagulation technology is a low-cost technology, produce larger and more stable flocs compared with those from other technologies, does not need chemical addition and produces less amount of sludge [6].

A simple EC system consists of two electrodes work as anode and cathode immersed in the polluted solution and connected to a DC power supply to provide a constant current for releasing metal cations from anode, resulting in flocs formation which contribute to pollutants removal.

According to faraday's law, the amount of cations released from the anode is dependent on the applied current as shown in equation **(1)**:

$$\omega = \frac{i\,t\,M}{z\,F} \tag{1}$$

Where, ω is the mass of metal cations generated (g), i is the current intensity (A/cm$^2$), M is the molecular weight (g/mol.), z is the number of electrons transferred per atom and F is Faraday's constant, 96,500 C/mol.

Using of iron electrodes generates a gelatinous suspension of Fe $(OH)_n$ which can remove pollutants from wastewater either by surface complexation or by electrostatic attraction followed by coagulation. The flocs formed can be easily removed from the aqueous solution either by flotation by $H_2$ gas bubbles at cathode or by sedimentation [7].

The prime objective of this study is to investigate the effect of operational parameters on the removal efficiency of Reactive Blue 19 (RB19) using EC. The effects of operational parameters such as initial pH, applied voltage, and initial dye concentration on the removal efficiency were investigated.

## II. MATERIALS AND METHODS

### A. *Electrocoagulation reactor:*

The EC reactor used in this study is shown in **Fig. 1.** Its components are a circular glass beaker (1 liter) with iron anode and cathode with dimensions of (3.5 cm x 10 cm x 2 mm) connected in parallel mode to a D.C. power supply (0-35 V) and inter-electrode distance is 2 cm.

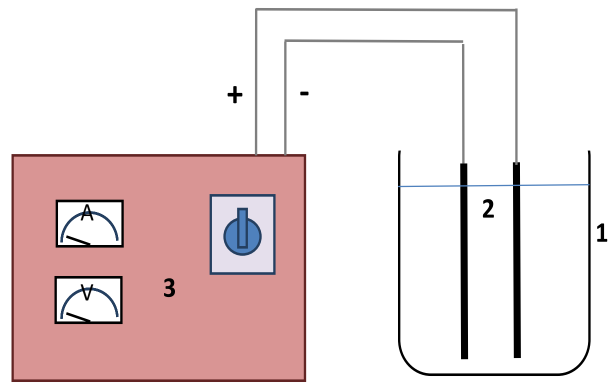


Fig. 1. EC reactor components (1) Beaker; (2) iron electrode (3) DC power supply

### B. *Reactive dye:*

A reactive blue dye, C.I. Reactive blue 19(RB19), was used in this research. Its general characteristics are illustrated in **Table 1**. and its chemical structure is shown in **Fig. 2**.

**TABLE I**
GENERAL CHARACTERISTICS OF RB19

| | |
|---|---|
| Molecular formula | $C_{22}H_{16}N_2Na_2O_{11}S_3$ |
| Commercial name | Sunzol blue RS 150% |
| Company | OH YOUNG INDUSTRIAL CO. LTD., South Korea |
| C.I. number | 61200 |
| λ max (nm) | 592 |

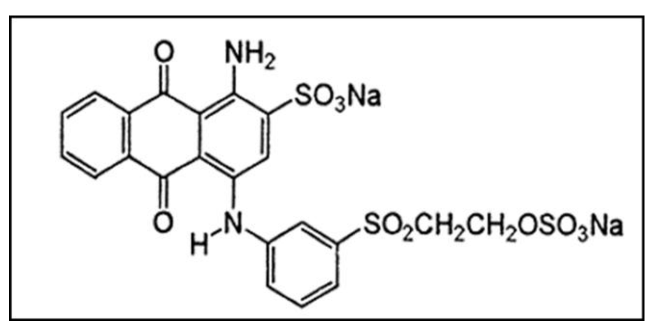


Fig. 2. Chemical structure of Reactive Blue 19

## III. Experiments, Procedures, Sampling and Analysis

A synthetic dye solution was prepared by dissolving 250 mg of RB19 in 1 liter of tap water and mixed by a magnetic stirrer in order to achieve complete mixing. The conductivity of the solution was enhanced by adding 1 g/l sodium chloride (NaCl). Sodium hydroxide (1M) or sulfuric acid (1M) was added to adjust the initial pH of the solution before each run and initial pH was measured by (Extech 341350A Oyster Series pH/Conductivity/TDS/ORP/Salinity Meter)

The iron plates were polished with sand paper then washed with distilled water, before each run. The losses in iron electrodes were determined by weighing the plates before and after each run using analytical balance (Citizen CY-204). An Avometer was used to check the applied voltage and the current during the experiment. All experiments were carried out at room temperature.

During EC process, a sample was taken every 5 minutes and filtered using filter paper (Whatman #1) then analyzed to determine dye concentration. The dye concentrations were determined using a UV-visible spectrophotometer (Shimadzu UV- 1601 PC, Japan) at a wavelength corresponding to the maximum absorbance of RB19 ($\lambda_{max}$ = 592 nm). Color removal efficiency ($R_{dye}$) was expressed as percentage and defined as:

$$\% R_{dye} = \frac{(C_o - C_e)}{C_o} \times 100 \qquad (2)$$

Where, $C_o$ and $C_e$ are the dye initial and effluent concentrations, respectively.

The energy consumption ($E_C$) and the electrode consumption ($M_C$) for dye removal under steady state conditions were calculated as follows:

$$E_C \left(\frac{kWh}{kg\ dye}\right) = \frac{U * i * t * 1000}{v * C_i * R_{dye}} \qquad (3)$$

$$M_C \left(\frac{kg}{kg\ dye}\right) = \frac{\Delta m * 1000}{v * C_i * R_{dye}} \qquad (4)$$

Where, U is cell voltage (V), i is current intensity (A), t is operating time (hour), v is volume (liter) of dye solution, $C_i$ is initial dye concentration (mg/l), $R_{dye}$ is color removal efficiency, Δm is the loss of metal (g).

## IV. Results and Discussion

*A. Effect of Applied Voltage :*

In order to investigate the effect of applied voltage on color removal efficiency, applied voltage of 5, 10, 15 and 20 Volt were used for an electrocoagulation process using an initial dye concentration of 250 mg/l, NaCl concentration of 1 g/l, and initial pH value 7 ± 0.5

**Fig. 3.** shows that dye concentration versus applied voltage are decreased with increasing operational time and then reaches a steady-state condition.

From **Fig. 3.** it is clear that the operational time can be decreased from 40 to 10 min by increasing the applied voltage from 5 to 20 volt, respectively also by increasing the applied voltage from 5 to 15 volt the dye concentration decreased from 220 to 14.6 mg/l then no significance change was observed by changing the applied voltage from 15 to 20 V, after 10 min reaction time.

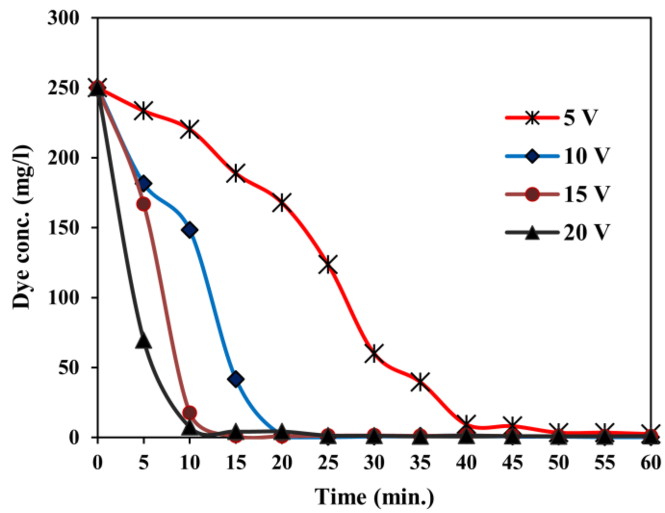


Fig. 3. Effect of applied voltage on the final dye concentration: initial dye concentration = 250 mg/l, volume of solution = 1 liter, NaCl Concentration = 1 g/ l, initial pH =7 ± 0.5

The energy ($E_C$) and electrode ($M_C$) consumptions were calculated using equations **(3)** and **(4)** under steady state condition for various values of applied voltage at reaction time required to obtain dye concentration less than 10 mg/l to investigate the effect of applied voltage on the operational cost.

**Fig. 4** shows that the energy consumption is increased from 9.1 to 36.83 kWh/kg dye removed by increasing the applied voltage from 5 to 20 volt, respectively. Also, the electrode consumption is increased from 0.94 to 1.93 kg of electrodes/kg dye removed with an increase in applied voltage from 5 to 20 volt, respectively.

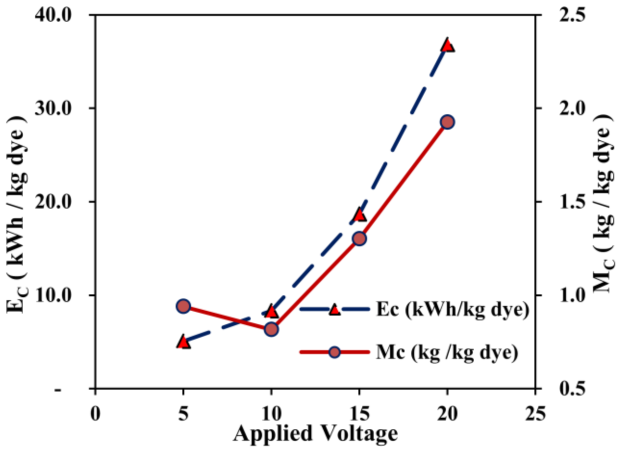


Fig. 4. Effect of applied voltage on energy and electrode consumptions: initial dye concentration = 250 mg/l, volume of solution = 1 liter, NaCl Concentration = 1 gm / l, initial PH =7 ± 0.5

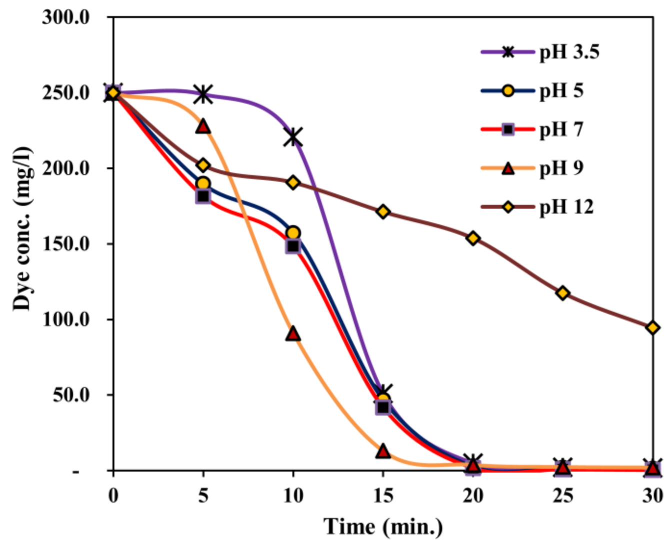


Fig. 5. Effect of initial pH on the final dye concentration: initial dye concentration = 250 mg/l, volume of solution = 1 liter, NaCl Concentration = 1 gm/ l, applied voltage = 10 V

It is clear that the energy and electrode consumptions are directly related to the applied voltage. This indicates that applied voltage inversely affects the energy and electrode consumption efficiency. Under experimental conditions, the optimum value of applied voltage was obtained at 10 volt as shown in **Fig. 4.**

The results are confirmed by *Song et al., 2008* who stated that an increase of the applied voltage increases the amount of metal ions generated from the anode, resulting in a higher amount of hydroxide flocs formation which can remove pollutants from solution [4]. *Chen, 2004* also reported that the chance of wasting electrical energy in heating up the solution increases with increasing the applied voltage which led to a significant decrease in current efficiency [8].

*B. Effect of Initial pH :*

Initial pH of the dye solution was adjusted to a value of 3.5, 5, 7, 9 and 12 by adding sodium hydroxide (1M) or sulfuric acid (1M) to study its effect on color removal efficiency using an initial dye concentration of 250 mg/l, NaCl concentration of 1 g/l and applied voltage of 10 V.

**Fig. 5** and **Fig. 6** illustrate the effect of initial pH on the final dye concentration. By raising the initial pH from 3.5 to 9, the dye concentration decreased from 50.75 to 13 mg/l then increase dramatically at pH equal to 12. **Fig. 6** shows that the minimum dye concentration was achieved at pH in the range of 7 to 9.

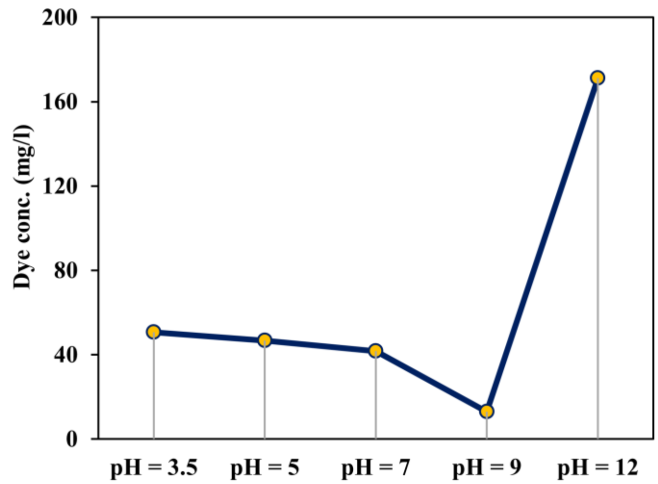


Fig. 6. Effect of initial pH on the final dye concentration: initial dye concentration= 250 mg/l, volume of solution = 1 liter, NaCl Concentration = 1 gm. / l, applied voltage = 10 V, EC treatment time = 15 min.

These results can be explained as at initial pH lower than 6, Fe $(OH)_3$ is in a soluble form {Fe $(OH)^{2+}$, Fe $(OH)^{2+}$} and at initial pH higher than 9, Fe $(OH)_6^{3-}$ or Fe $(OH)_4^-$ ions may be present, this inversely affect the capacity for color removal [9]. The results show that the lowest dye concentration has been achieved at initial pH range from 6 to 9 because Fe $(OH)_3$ which has a major role in color removal has less solubility in this pH range [10]

### C. *Initial Dye Concentration Effect :*

The effect of initial dye concentration on color removal efficiency was investigated using 150, 250, 350 mg of RB19/l and NaCl concentration of 1 g/l, initial pH value 7 ± 0.5, and applied voltage of 10 volt.

**Fig.7** shows that after 10 min reaction time the removal efficiency is 86.2% for a solution of initial dye concentration 150 mg/l and 13.0% for a solution of initial dye concentration 350 mg/l, respectively.

It also shows that as the initial dye concentration increased, the reaction time required to achieve high removal efficiency increased. It may be explained by the fact that according to faraday's law Eq.1 a constant number of metal ions are generated from the electrode at constant electric current for all dye concentrations so that in the case of high dye concentrations and short reaction- time, insufficient amount of hydroxide flocs formed which adsorb dye molecules from the solution [10].

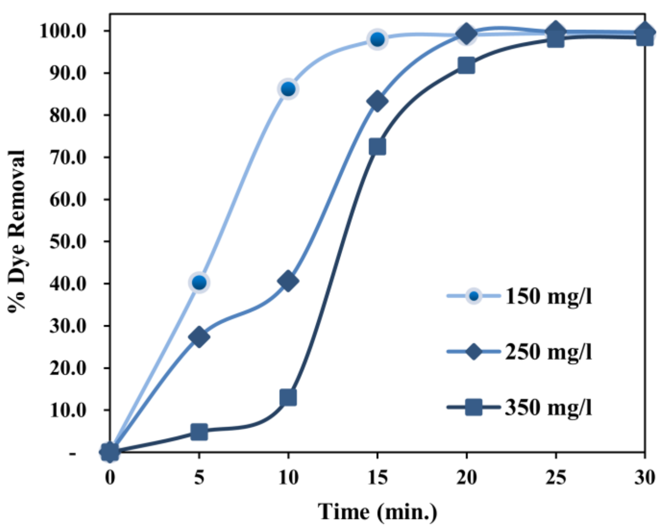


Fig. 7. Effect of initial dye concentration on the dye removal efficiency: volume of solution = 1 liter, NaCl Concentration = 1 gm/ l, applied voltage = 10 V, initial PH =7 ± 0.5

However, the results in **Fig. 8** shows that, after 15 min reaction time, the energy consumption and electrode consumptions per kg of dye removed decrease with an increase in dye concentration under the present experimental conditions which indicated that the higher concentration of dye molecules increase the adsorption capacity of flocs [4].

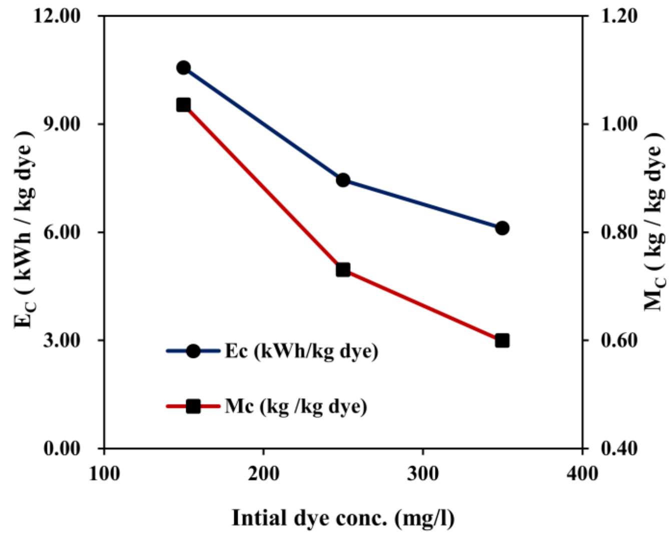


Fig. 8. Effect of initial dye concentration on energy and electrode consumption: volume of solution = 1 liter, NaCl Concentration = 1 g / l, applied voltage = 10 V, initial pH = 7 ± 0.5

## V. Conclusion

This research investigates the removal efficiency of Reactive Blue 19 dye (RB19) from a synthetic dye solution using a batch electrocoagulation (EC) reactor with iron electrodes. The effect of various operation parameters such as applied voltage, initial pH and initial dye concentration on dye removal efficiency were studied. Increasing applied voltage decreases the operating time required to achieve plateau. However, the energy consumption and electrode consumption increase by increasing the applied voltage. The increase in the initial dye concentration from 150 to 350 mg/l decreases the color removal efficiency from 86.2 to 13 %, respectively. The optimum operational conditions can be achieved using applied voltage of 10 V, operating time of 20 min., and initial pH in the range of 7 to 9.

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