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Textile Effluent Degradation by Photoelectrolytical Process

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Abstract

Methodologies used in textile effluents treatment consist in different ways: biological, chemical and physical-chemical. Thus, electrochemical and photochemical processes are promising such as an alternative or complementary treatment. Therefore, an experimental photoelectrolytic system was used to treat a simulated effluent containing Remazol Navy Blue dye (C.I. Reactive Blue 89). This photoelectrolytic reactor presented a commercial anode ($70TiO_2/30RuO_2$.) and an UVC lamp. The results demonstrated the treatment was able to degrade the dye in good cost-efficiency performance.

Keywords: Dye, Electrochemical, Photochemical, C.I. Reactive Blue 89

1. Introduction

New technologies in chemical industry provide a greater number of compounds and consequently new molecules of textile dyes are available every year. It is estimated that there are at least 8,000 different textile dyes (Zanoni & Carneiro, 2001). Hence, textile effluents become complex mixtures and new treatment methods are needed. Without proper treatment, these dye solutions are very hazardous to the environment especially to aquatic ecosystems (Catanho et al., 2006). Environmental impact is due to effluent color, toxicity and chemical stability of the dyes in water. The environmental impact is due to effluent color, toxicity and chemical stability of the dyes in water, which endangers the ecosystem balance and the food chain (Silva et al., 2009).

In textile industry, 12% of organic dyes are discharged in effluents during manufacturing and dyeing stages (Holme, 1984). Furthermore, some dye molecules and their subproducts are carcinogenic and mutagenic (Catanho et al., 2006) and demonstrate acute toxicity (Peralta-Zamora et al., 2002). Moreover, these effluents often present high levels of heavy metals (Catanho et al., 2006). Therefore, the development of efficient and safe ways to degrade dyes in effluents is important for maintenance a good environmental quality.

There are many different methodologies in textile effluent treatment such as biological processes in biodegradation and biosorption by microorganisms (Aksu, 2000; Beydilli, 2000; Bertazzoli & Pelegrini, 2002). Physicochemical methods also are used to degraded dye compounds by: electrolytic process (Pelegrini et al., 1999), UV oxidation (Georgiou et al. 2001, Akyol & Baramoglu, 2005), hydrogen peroxide, etc. Electrochemical and photochemical treatments are very promising for organic effluents. Besides, they can contribute as an alternative or complementary methodology for highly colored effluents especially with reactive dyes.

In effluents with reactive dyes, the treatment needs advanced technology due to their molecular structures that is unlikely to be degraded by biological processes. Chomophore group AZO is responsible for low biodegradability of these compounds and their chemical bonds are strong enough to not be disrupted by biological processes (Araújo & Yokoyama, 2006; Al-Degs et al., 2000).

Thus, the study aimed to evaluate the treatment of a simulated textile effluent with the reactive dye Remazol Navy Blue (C.I. Reactive Blue 89). It was used a photoelectrolytic system to optimize the process for commercial use.

2. Material and Methods

A photoelectrolytic system was used in treatment of the simulated textile effluent (Figure 1). This system contained: an electrolytic reactor, pipes, ultraviolet lamp, flow meter, pump and taps. An anode of titanium and ruthenium (70%TiO_2/30%RuO_2) and a cathode distant 3.00 cm each other constituted the electrolytic system. Besides, the photochemical process occurred in a stainless-steel chamber with an 1,600 W UVC lamp and the control panel.

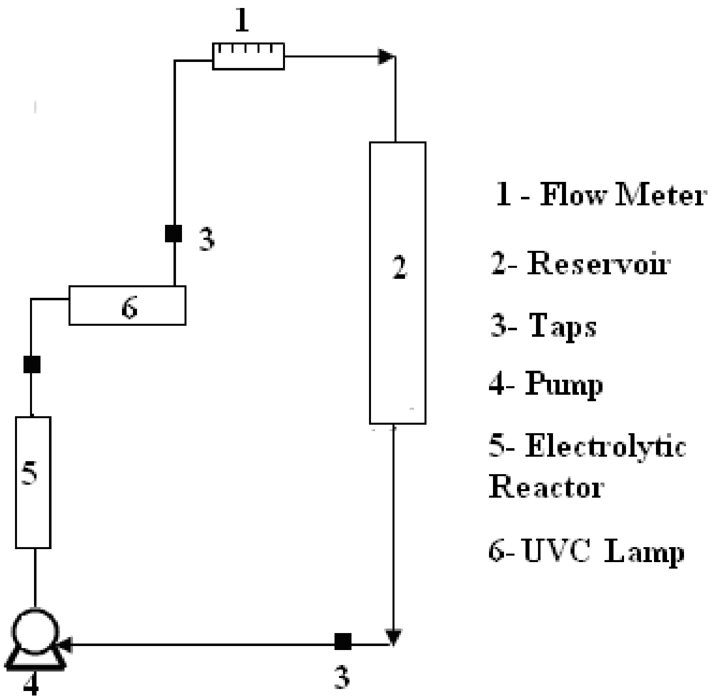

Figure 1. Scheme of photoelectrolytic system

Photoelectrolytic system had a maximum capacity of 7.0 L and its dimensions were 80 x 40 x 130 cm. Besides, a TECTROL XR1A of 15 V/10 A equipment was used for electrodes polarization.

Simulated textile effluent was prepared as a solution with Remazol Navy Blue and supporting electrolyte in pH 3.5 (Sauer et al., 2002). Dye solution concentrations reached a maximum of 0.192 $g{\cdot}L^{-1}$ and the supporting electrolytes were Na_2CO_3 (1.32 or 3.00 $g{\cdot}L^{-1}$) and NaCl (40.00 or 10.00 $g{\cdot}L^{-1}$) or Na_2SO_4 (14.20 $g{\cdot}L^{-1}$).

Firstly, the simulated effluent (4.00 L) was placed in the reservoir and after pumped through the system on a vertical flow direction in a flow rate (Q) of 500 $L.h^{-1}$ (Figure 1). Batch recirculation promoted the effluent pass inside the electrolytic reactor underwent current of 5.0 A (current density was 125.0 $m{\cdot}cm^{-2}$) and in the UVC chamber for 60 minutes. Photolytic effect by UV lamp occurred only for 3 minutes in order to avoid overheating.

Thus, six samples in different times of treatment were analyzed: 0, 3, 5, 15, 30 and 60 minutes. Color removal was determined by absorbance measures in UV-Vis spectrophotometer (Shimadzu® UV-VIS 2401 PC) at 599 nm.

3. Results and Discussion

Primarily, the treatment system was performed in order to evaluate color removal in different dye concentrations. It was observed that different initial concentrations of dye (C_i) influenced

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the color removal rate (Figure 2).

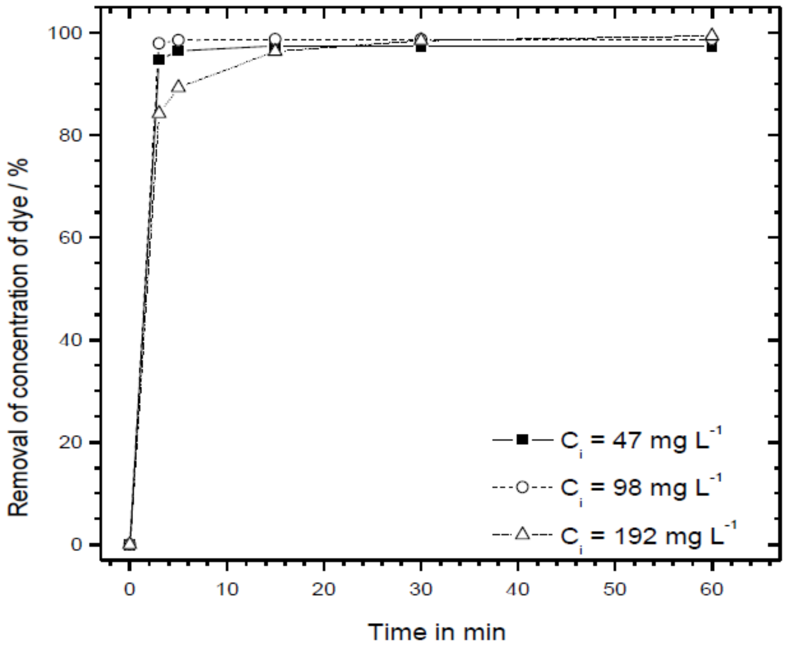

Figure 2. Color removal in different initial concentrations of the dye Remazol Navy Blue - C_i (J = 125 mA cm^{-2}, Q = 500 L h^{-1}, pH 10.61, [NaCl] = 10.00 g·L^{-1}, [Na_2CO_3] = 1.32 g·L^{-1} and UV connected at the first 3 minutes of treatment)

In Table 1, the treatment cost was calculated according to kWh price in Brazil as USD 0.108 (www.aneel.gov.br). It was not considered the salt costs (NaCl and Na_2CO_3) once they are normally present in real textile effluent.

Table 1. Treatment cost in 5 minutes treatment in different initial concentrations of the dye Remazol Navy Blue

Dye (mg·L^{-1})	Color removal (%)	Lamp cost (USD·m^{-3})	Electrolysis cost (USD·m^{-3})	Total Costs[1] (USD/m^{-3})	K (m·min^{-1} mg·L^{-1})
47	96.5	1.62	0.0685	1.6885	0.116
98	98.5	1.62	0.0675	1.6875	0.137
192	89.3	1.62	0.0675	1.6875	0.010

Note: [(1)]Not considering pump consumption.

Better efficiency as 96.5% in color removal for dye initial concentration of 192 mg·L^{-1} was obtained after 15 minutes treatment. However, the cost of photoelectrolytic system was higher due to kWh consumed in electrolytic reactor.

The simulated textile effluent treatment was also analyzed according to supporting electrolyte. Thus, different compositions and initial concentrations of salts were used as showed in Figure 3.

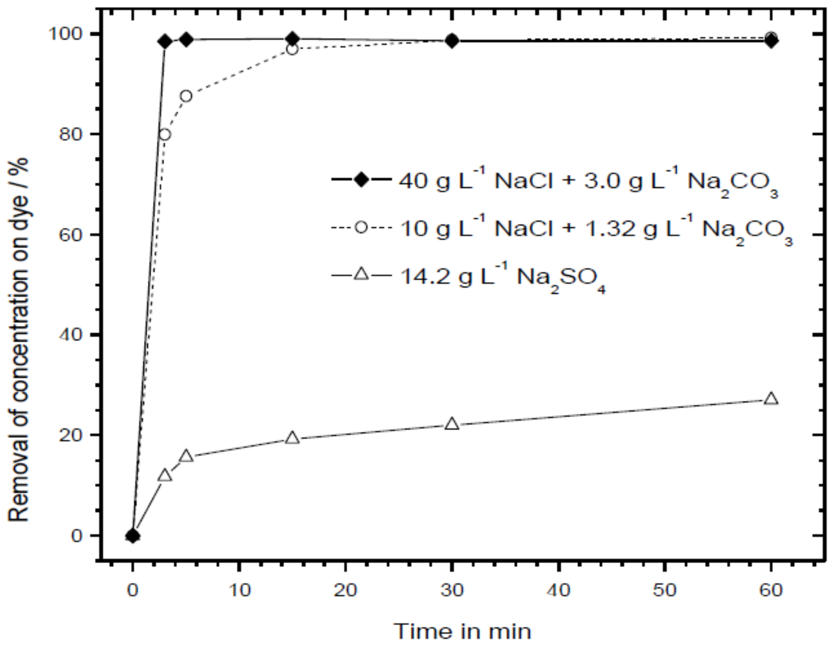

Figure 3. Color removal (dye Remazol Navy Blue) in different initial concentrations of electrolytes (J = 125 mA cm^{-2}, Q = 500 L h^{-1}, pH 10.61, C_{dye} = 98 mg·L^{-1}, UV connected at the first 3 minutes of treatment)

The results demonstrated that using NaCl and Na_2CO_3 had greater color removal. Also, higher concentration leads to better removal rates. On the other hand, it was observed a low efficiency when Na_2SO_4 was the supporting electrolyte, even in 14.2 g·L^{-1} concentration.

Table 2. Treatment cost in 5 minutes treatment in different initial concentrations of electrolytes

Electrolyte (g·L^{-1})	**Color Removal (%)**	**Lamp cost (USD·m^{-3})**	**Electrolysis cost (USD·m^{-3})**	**Electrolyte cost$^{(2)}$ (USD·m^{-3})**	**Total Costs$^{(1)}$ (USD·m^{-3})**	**K (m·min^{-1} mg·L^{-1})**
40.0 NaCl + 3.0 Na_2CO_3	99.0	1.62	0.055	0.00	1.675	0.124
10.0 NaCl + 1.32 Na_2CO_3	87.5	1.62	0.075	0.00	1.695	0.008
14.2 Na_2SO_4	15.7	1.62	0.075	7.80	9.495	0.00019

Notes: $^{(1)}$ Not considering pump consumption. $^{(2)}$ Na_2SO_4 – USD 11.00 kg.

Similarly, better efficiency as 97.0% in color removal using 10 $g{\cdot}L^{-1}$ NaCl + 1.32 $g{\cdot}L^{-1}$ Na_2CO_3 was obtained after 15 minutes treatment. However, the cost of photoelectrolytic system was higher due to kWh consumed in electrolytic reactor.

Reactive molecules and ions are able to oxidize organic compounds (Cossu et al., 1998). Hence, results showed that the chloride (NaCl) was responsible for the increased efficiency of the electrolytic process.

About the treatment cost, Mierzwa et al. (2008) related the financial issue in drinking water treatment. It was established that conventional systems generally cost USD 0.20/m^3, but most of processes spends more in an efficient condition. Thus, higher values presented in Table 1 and 2 can be viable due to the hazardous effluent such a textile dyes (Peralta-Zamora et al., 2002; Catanho et al., 2006).

Mathematical modeling was realized to establish the relation of the volume of the reservoir (4.00 L) and the volume of the reactor (0.015 L). The reactor operation was in batch and single pass and due to this fact kinetic analysis was performed color removal. The value of apparent clearance rate constant (k) depends on the electrode and the solution. Therefore, Equation 1 is able to extend for each condition and current flow in treatment system:

$$\frac{1}{C_{(t)}} - \frac{1}{C_{(t=0)}} = -k\frac{A}{V_{(tot)}}t \tag{1}$$

where: $C_{(t)}$ is the color rate in time t; $C_{(t=0)}$ is the initial color value; A is the anode area; $V_{(tot)}$ is the volume of solution; t is the treatment time; k is the apparent clearance rate constant ($m{\cdot}min^{-1}$ $mg{\cdot}L^{-1}$ for adjustment of order 2).

According to Equation 1, the curves in Figures 2 e 3 presented a second-order kinetic fit in 5 minutes of treatment. Moreover, constant k provides scaling the system under different conditions of current density and flow recirculation.

4. Conclusion

Photoelectrolytic system was effective in the simulated textile effluent treatment with the Remazol Navy Blue. UVC lamp associated with electrolytic reactor promoted the dye molecule degradation and using NaCl and Na_2CO_3 as supporting electrolyte had greater color removal. Besides, the treatment cost was compatible for deployment in industries in large-scale used due to its efficiency in handling this hazardous solution.

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