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Dyeing of cotton with reactive dyestuffs: the continuous reuse of textile wastewater effluent treated by Ultraviolet / Hydrogen peroxide homogeneous photocatalysis

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ABSTRACT

Ten differents dyeings were made using reuse water obtained from effluent after treatment by homogeneous photocatalysis. Before and after the UV/H_2O_2 treatments, the concentration of sodium chloride (NaCl), the absorbance (Abs) and the amount of total organic carbon (TOC) were monitored. All rates of decolorization were above 92% and the removal of TOC was above 88% in all treatments. Compared with the same dyeings made with deionized water, the total deviation (ΔE^*) between the colors did not exceed 1.05. Currently, for a monthly production of 20 dyeings of 100 kg each, 160 m^3 of water is consumed and an equal volume of effluent is generated. The same dyeings made by the process proposed in this study, with an addition of 10 m^3 of water after 20 dyeings, would consume just 60 m^3 of water, without effluent discharge containing high amounts of organic matter and high values of absorbance.

1. Introduction

The world population growth is directly linked to the availability of drinking water, the increase in agricultural production and industrial growth. Improvements in these areas are developed with advanced technologies aimed at increasing production and streamlining their costs. Dyestuffs are used to color the final products of different industries, such as textiles, pulp and paper, cosmetics, food, leather and rubber. The generation of these products leads to the formation of effluents contaminated with all classes of dyestuffs (Hessel et al., 2007; Madeira, 2011). Besides that, sustainable production applications have been done in all over the world. Alkaya and Demirer (2014), for example, obtained a decreased of 40.2% in the water consumption in a woven fabric manufacturing mill, reducing the wastewater generation in 43.4%.

Despite being one of the pioneering fields to incorporate environmental practices, the textile industry is also characterized by high consumption of water, fuel and chemicals and there are many environmental problems associated with textile wastewater. With regard to global water scarcity, the treatment and recycling of wastewater effluent in the textile industry can help alleviate some of the burden; therefore, the continuous search for improvements in textile water reuse processes is essential (Bastian and Rocco, 2009; Burkinshaw and Kabambe, 2011; Cardoso et al., 2012; Valh et al., 2011).

Of all dyed textile fibers, cotton is the most commonly used, and more than 50% of cotton produced is dyed with reactive dyes. It is estimated that approximately 10–60% of reactive dyes are lost during textile dyeing, producing large amounts of colored effluents. The dye-containing effluent discharged from these industries can adversely affect the aquatic environment by impeding light penetration and consequently inhibiting the photosynthesis of aqueous flora (Allègre et al., 2006; Cardoso et al., 2011a; 2011b; Martins et al., 2011).

In this sense, research has been undertaken with the aim of finding new dyes; eco-friendly, to replace the current chemical dyes; as Sivakumar et al. (2011) that extract dyes from green wattle bark, marigold, pomegranate rinds, 4'o clock plant flowers and

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cocks comb flowers by ultrasound technique. Islam et al. (2013) showed traditional (maceration and soxhlet) and innovative (ultrasound, microwave and supercritical carbon dioxide) extraction methods applied to obtain dyes from various vegetable sources and from different parts of plants, such as: from *Acacia arabica* bark, from *Alkanna tinctoria* root, from *Bixa orellana* seeds, from *Datisca cannabina* leaves, from *Haematoxylan campechianum* heartwood and from *Garcinia mangostana* fruits.

According to Shahid et al. (2013) not the existence of natural dyeing on a commercial scale is one of the biggest impeding factors of no use of natural dyes in modern textile industry. However, there are some discrete group of researchers studied the availability of raw material, product properties, renewability and standardization for large scale production of natural dyes. However, in the near future, the devotion attention of these researchers and practitioners show how to make these environmentally friendly products viable to environmental and socio-economic to modern textile industry (Islam et al., 2013).

In recent years, advanced oxidation processes (AOPs) have been applied as an alternative for treatment of textile wastewater effluents. The AOPs are processes in which the main oxidizing agent is the hydroxyl radical (·OH), which is generated by the application of UV irradiation with substances such as hydrogen peroxide (H_2O_2) (Bezerra et al., 2013; Günes et al., 2012; Wang et al., 2011) or semiconductors such as titanium dioxide (TiO_2) (Lin et al., 2013; Mattle and Thampi, 2013; Nenavathu et al., 2013; Rosa et al., 2012a; 2012b). Other types of treatments have been investigated, such as photocatalysis with nanoparticles of selenium-doped ZnO (Wegermann et al., 2013) and catalysis by mononuclear manganese complex II (Oliveira et al., 2009) with both treatments obtaining rates of decolorization above 90%

With high potential for decolorization and application for reuse of treated textile wastewater effluent, AOPs are viable and competitive treatment alternatives when compared with conventional processes for effluent treatment. In addition, conventional biological treatments may be ineffective in treating for sludge formation and the large number of aromatic rings present in organic dye compounds (Braúna et al., 2009; Kusic et al., 2013; Pang and Abdullah, 2013; Rosa et al., 2012).

2. Experimental

2.1. Dyeings

Ten dyeings for ten different colors were performed using the Mathis Alt-1 dyeing machine. The recipes for the dyeings, including the necessary amounts of dyestuff and auxiliaries, are shown in Table 1 and were applied according to instructions of the dyestuffs manufacturer. The steps A to H represent the sequence of dyestuff and auxiliaries addition during the dyeings.

The commercial synthetic dyes, bifunctional vinylsulfone and monochloro-*s*-triazine, C.I. Reactive Yellow 145 (monoazo, 1026 g mol^{-1}), C.I. Reactive Orange 122 (monoazo, 1034 g mol^{-1}), C.I. Reactive Red 239 (monoazo, 1136 g mol^{-1}), C.I. Reactive Blue 222 (diazo, 1357 g mol^{-1}) and vinylsulfone C.I. Reactive Blue 21 (phthalocyanine, 1092 g mol^{-1}) were supplied by a local manufacturer, Golden Química, with each dye having a purity higher than 90%.

The dyeings were performed strictly according to instructions of the dyestuffs manufacturer with a liquor ratio equal to 10:1. All stages of the entire process such as bleaching, dyeing and washing are shown graphically in Fig. 1.

Samples were collected from each dyeing process and stored for photochemical treatment and subsequent reutilization.

2.2. Effluent treatment

2.2.1. Photochemical step

The effluent was diluted with water, in the ratio of 1:4. The pH was adjusted to 7, and 2.27×10^{-2} mol of H_2O_2 was added in aliquots of 1 L (APHA, 2005). Afterward, the sample was exposed to UV-C radiation (provided by two Philips TL 6 W lamps) at 298 K until complete decolorization. During photochemical reactions, 10 mL of liquid sample was taken out at 15-min time intervals to assess the absorbance decrease using the Konica Minolta CM-3600d. To calculate the decolorization efficiency, the Eq. (1) was used (Rosa et al., 2014).

$$D_E(\%) = \left(1 - \frac{Abs_0}{Abs_f}\right) * 100 \quad (1)$$

where D_E = decolorization efficiency (%); Abs_o = initial absorbance; and Abs_f = final absorbance

2.2.2. Concentration of electrolytes

After the photochemical treatment, the concentration of electrolytes was determined by measuring conductivity (Quimis Q975A Conductivimeter) and using the calibration curve shown in Fig. 2.

The conductivity was used to determine the concentration of sodium chloride (Eq. (2)), which was discounted from the next dyeing (Rosa et al., 2014).

Table 1
Amount of dyestuffs and auxiliaries, from recipes 1 to 10.

Step	Dyestuff/Auxiliary	Colour									
		2205	2286	2201	2237	2269	2209	2215	2203	2241	2297
A	H2O2 50%(mL L^{-1})	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	NaSiO3 (g L^{-1})	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	NaOH 50 °Bé (mL L^{-1})	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Detergent (g L^{-1})	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Sequestering Agent (g L^{-1})	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
B	CH3COOH (neutralize bleaching-mL L^{-1})	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
C	Catalase (%)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
D	NaCl (g L^{-1})	20	25	30	30	30	35	40	50	50	60
E	C.I. Reactive Yellow 145 (%)	0.30	0.10	0.10	0.24	0.60	0.12	0.92	0.12	2.00	2.40
	C.I. Reactive Orange 122 (%)	–	–	–	–	–	–	–	–	0.89	2.10
	C.I. Reactive Red 239 (%)	–	–	0.20	0.04	–	0.26	0.35	–	0.14	0.04
	C.I. Reactive Blue 222 (%)	–	0.20	0.20	0.26	0.05	0.60	0.24	–	–	–
	C.I. Reactive Blue 21 (%)	0.14	–	–	–	0.09	–	–	2.00	–	–
F	NaCO3 (g L^{-1})	8	8	10	10	10	10	10	15	15	15
G	CH3COOH (neutralize dyeing-mL L^{-1})	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
H	Leveling Agent (g L^{-1})	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00