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Competitive adsorption and optimization of binary mixture of textile dyes: A factorial design analysis

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KEYWORDS

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Abstract In this paper, a study of simultaneous adsorption of mixture dyes of Basic Blue 41 and Basic Yellow 28 in binary system was done using two types of activated carbon and compared with a single dye system in a batch mode. A competitive adsorption between the two cationic dyes was observed and it was noticed that Basic Blue 41 was favored. Kinetics of each dye in single and binary systems was found to follow pseudo-second-order rate kinetic model, with a good correlation (higher than 0.99). The single component equilibrium data were analyzed using the Langmuir and Freundlich isotherms. Overall, the Langmuir isotherm showed a better fitting for all adsorptions under investigation in terms of correlation coefficient. As the binary adsorption is competitive, extended Langmuir models could not predict the binary component isotherm well. The essential parameters which affect the removal efficiency of binary mixture solution such as pH, temperature and adsorbent type were optimized using full factorial design methodology. Effect of parameters and interaction were analyzed using Pareto chart, main effect and interaction effect. In various industrial effluents like textile industries and plant-produced water, dyes are existent in mixture form. So, this work might be of great benefit in knowing to remove the used dyes.

1. Introduction

When analyzing the wastewater which is produced from Industrial textile, it was observed that many dyes coexist simultaneously. The removal of these dyes from water can be achieved via several techniques such as bio-treatment (El-Sheekh et al., 2009; Khataee et al., 2012a–c, 2011a,b), adsorption (Eren et al., 2010; Dogan et al., 2007; Karaca et al., 2013), flocculation-coagulation (Canizares et al., 2006), photo catalytic degradation (Rezaee et al., 2012; Khataee et al., 2012a–c, 2011a,b), chemical oxidation (Khataee et al., 2011a, b; Sun et al., 2012) etc.

The adsorption technique has proven to be an effective and attractive process for the treatment of these dye-bearing wastewaters (Crini et al., 2006). Earlier, the production of activated carbon using various agricultural residues like, coconut shell, groundnut shell, cassava peel, corn cob, olive stones and walnut shells, palm kernel shell, coir pith, pecan shell, fruit stones and nutshells, rubber seed coats has been attempted (Singh and Arora, 2011; Ioannidou and Zabaniotou, 2007; Amuda et al., 2007; Malik et al., 2007; Sudaryanto et al.,

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Table 1 Factors and levels used in factorial design study.

Parameter name study	Abbreviation	Low (−1)	High (+1)
pH	pH	2	12
Temperature (K)	T	298	328
Type of adsorbent	TA	C-ZMN	C-PAN

2006; Cao et al., 2006; Martinez et al., 2006; Jumasiah et al., 2005; Bansode et al., 2004) because of their high surface area, microporous character and the chemical nature of their surface.

Recently, for ongoing program research we have used some materials of animal origin to remove dyes from aqueous media (El Haddad et al., 2014; Slimani et al., 2014, 2011).

Much of the work on the adsorption of dyes by various kinds of adsorbents has been focused on the uptake of single dyes. Since industrial effluents may contain several dyes, it is necessary to study the simultaneous sorption of two or more dyes and to quantify the interference of one dye with the sorption of the other. Thus, the studies on the equilibrium and kinetics of dyes adsorption from multi-component systems are very important. In this fact, factorial design is employed to reduce the total number of experiments in order to achieve the best overall optimization of the system.

Factorial design experiments allow the simultaneous study of the effects that several factors may have on the optimization of a particular process. On the other hand, factorial design allows measuring the interaction between different group of factors. The high and low levels defined for the 2^3 factorial designs are listed in Table 1.

The aim of the present paper is to achieve the followings studies such, the feasibility of using Persea Americana Nuts Carbon (C-PAN) and Ziziphus Mauritiana Nuts Carbon (C-ZMN) as adsorbents for the individual and simultaneous removal of BB41 and BY28 dyes from aqueous solutions, kinetics for the two dyes in single and binary solutions, Equilibrium isotherms for the single adsorption of dyes were analyzed using the Langmuir and Freundlich models, in binary mixture solution the data were analyzed using the extended Langmuir model and finally to examine in binary solution, the effects and the interactions by optimization of various parameters such as pH, temperature and type of adsorbent.

2. Materials and methods

2.1. Materials

The *Persea americana* and *Ziziphus mauritiana* nuts were used to prepare the activated carbon of C-PAN and C-ZMN successively. The mentioned Nuts were washed with distilled water and dried in a drier at ambient temperature for several days. These later were dubbed the names PAN and ZMN. The carbonization of PAN and ZMN was carried out using an appropriate weight and 25 mL concentrated phosphoric acid with a mass ratio (1:4) The activation was completed by heating at temperature 500 °C for 1 h producing a black carbonaceous residue. The activated carbon was repeatedly washed with hot distilled water until the pH of the washing solution reached 6–6.5. The product was dried at 105 °C for 2 h and kept in tightly closed plastic container.

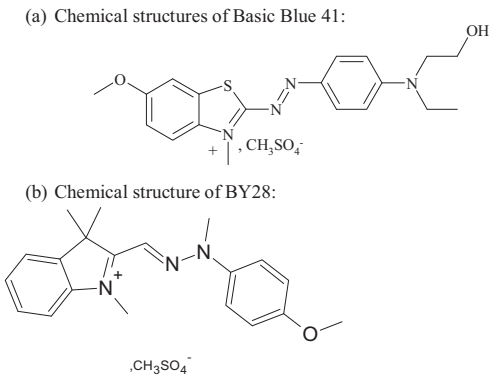

Figure 1 Chemical structures of Basic Blue 41 and BY28.

Basic Blue 41 and Basic Yellow 28 were used as received without any purification; their colors are stable within the pH range of the study. The chemical structures of BB41 and BY28 are given in Fig. 1. A stock solution of 100 mg/L was prepared by dissolving the required amount of each dye in distilled water. The characterization of adsorbents achieved by FT-IR spectroscopy and Scanning Electronic Microscopy (SEM) images were obtained with HITACHI-S4100 equipment operated at 20 kV. Adsorption–desorption isotherms of nitrogen at −196 °C were measure with an automatic adsorption instrument (NOVA-1000 Gas Sorption analyzer) in order to determine surface areas and total pore volumes.

2.2. Adsorption experiments

Dye removal experiments were performed by mixing known weights of each adsorbent in 50 mL of single dye solution in flasks at 25 °C. The effects of initial dye concentrations (25–100 mg/L) on adsorption capacity were investigated. The required combinations of Basic Yellow 28 and Basic Blue 41 were obtained for binary pollutants mixture by diluting 1000 mg/L of the stock solutions and mixing them.

The percentage of the removal efficiency of each dye in binary system was compared with that of their pure state. In this investigation of mixture dyes removal using C-PAN and C-ZMN, the percentage removal may depend on pH, temperature and adsorbent type. The other variables such as the initial concentration of each dye (25 mg/L), time of agitation which is suitable for equilibrium at 30 min and adsorbent dosage (0.2 g/L) were kept constant. At any time, the residual dye concentration in the reaction mixture was analyzed by centrifuging the reaction mixture and then measuring the absorbance by UV–Visible spectroscopy of the supernatant at the wavelength that is corresponding to the maximum absorbance of 438 nm for BY28 and 606 nm for BB41 respectively. The removal dye percentage (%) can be calculated as follows:

The amount of equilibrium adsorption q_e (mg/g) was calculated using the formula:

$$q_e = \frac{C_0 - C_e}{W} V \quad (1)$$

where C_e (mg/L) is the liquid concentration of dye at equilibrium, C_0 (mg/L) is the initial concentration of the dye in solution. V is the volume of the solution (L) and W is the mass of dye biosorbent (g)

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