15° ENCONTRO BRASILEIRO SOBRE ADSORÇÃO
15th Brazilian Meeting about Adsorption

Kinetics of neutral red dye removal by sugar cane bagasse

Jumara Silva de Sousa[1], Nicole Novelli do Nascimento[2], Rosângela Bergamasco[1], Angélica Marquetotti Salcedo Vieira[3]*

[1]*Postgraduate Program in Chemical Engineering, State University of Maringá, Av. Colombo, 5790, Maringá, PR, 87020-900, Brazil.*
[2]*Postgraduate Program in Food Science, Centre of Agrarian Sciences, State University of Maringá, Av. Colombo, 5790, Maringá, PR, 87020-900, Brazil.*
[3]*Department of Food Engineering, State University of Maringá, Av. Colombo, 5790, Maringá, PR, 87020-900, Brazil.*

Abstract

High quantities of dyes are used in various industries every year, which are not biodegradable and which, when discharged into the aquatic environment, can influence human and animal health and cause damage to the environment, since they can be carcinogenic and toxic. In this sense, the need for effective treatments to remove these pollutants has grown. Adsorption has gained prominence due to its efficiency and cost-effectiveness. For this reason, this study used adsorption as a mechanism for removing the neutral red cationic dye. Raw sugarcane bagasse was used as the adsorbent. The results obtained showed that the residue was capable of removing the dye from water, with a constant adsorption capacity of 22.8 mg g-1 over a contact time of 600 min. It is assumed that the mechanism that favored the removal of the dye was chemisorption, since the Elovich model was the one that best fitted the experimental data with the lowest χ^2.

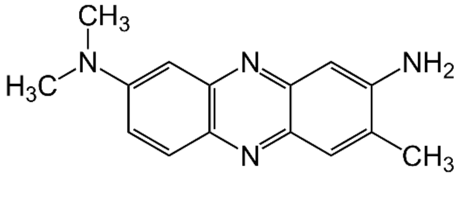
Keywords: biosorbent; sugarcane bagasse; neutral red.

1. Introduction

Dyes and pigments are used extensively in the textile, paper, plastic, leather, food and cosmetics industries. However, the release of these products into effluents can pose a high risk to the environment and to the health of the population, as they are carcinogenic, even in small quantities [1].

Neutral red (NR) (Figure 1) is a cationic dye that is widely used as a pH indicator and in biological research [2], but due to its toxic nature, measures are needed to eliminate these substances and prevent an increase in environmental pollution.

Figure 1: Chemical structure of NR dye.



In this respect, methods based on mass transfer are used to remove dyes, such as coagulation, flocculation, membrane filtration, ion exchange and adsorption [3].

Of the methods currently used, adsorption has stood out in wastewater purification because it is a simple and practical technology [4,5].

Among the variety of materials that can be used as adsorbents, agricultural and forestry residues have been explored in research as potential adsorbents [6].

Sugarcane bagasse is an agricultural residue rich in cellulose, hemicellulose and lignin, but it has become a challenge for industries and the environment due to the high amount of bagasse generated [7].

Given this reality, a viable alternative for solving this problem is to use this waste as an adsorbent.

With this in mind, the aim of this research is to evaluate the adsorption capacity through the kinetic study of sugar cane bagasse as an adsorbent in the removal of the neutral red dye.

2. Materials and methods

This study was carried out at the Chemical Engineering Department (DEQ), in the Environmental Management, Control and

Preservation Laboratory (LGCPA), at the State University of Maringá, Maringá campus.

The neutral red dye was purchased by INLAB Confiança (Diadema/SP). The sugarcane bagasse was purchased at a local market in Maringá.

The neutral red solution was prepared by dissolving the dye in distilled water while stirring.

2.1 Biosorbent preparation

The sugarcane bagasse (SB) was washed thoroughly with distilled water under agitation. The washing process was repeated until the water was free of dirt. The SB was then placed in an oven with air circulation at 60ºC for 24 hours to remove the moisture. They were then crushed and standardized at 600 µm.

2.2 Adsorption Assay

The tests were carried out in batches and in triplicate. Initially, mass testing was carried out. For this, three masses were used: 0.010 g, 0.015 g and 0.020 g, which were kept in contact with the NR for 900 min.

The mass with the highest adsorption capacity was used for the kinetic study. The parameters established for these studies are shown in Table 1.

Table 1. Parameters evaluated in the adsorption tests.

Experimental conditions	
Mass (g)	0.01-0.02
Volume (mL)	25
pH	7
Initial concentration (mg L^{-1})	10
Contact time (min)	0 a 900
Stirring speed (rpm)	150

After the reaction times, the samples were filtered using a 22 µm membrane and the final and initial concentrations were measured using a UV-VIS spectrophotometer (Metash - model 5100) at a wavelength of 530 nm.

Subsequently, the adsorptive capacity (Equation 1) and the removal percentage were calculated (Equation 2).

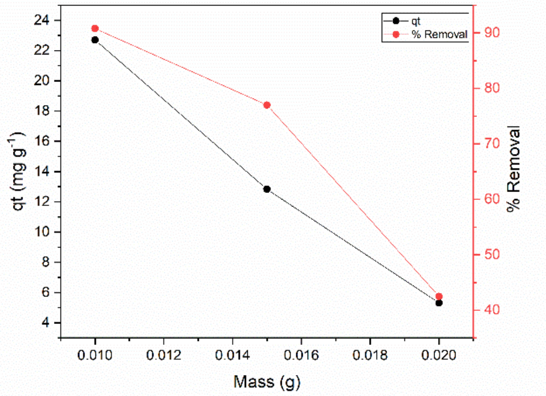
$$q_e = \frac{(C_0 - C_e) \times V}{m} \tag{1}$$

$$R_e = \frac{(C_0 - C_e) \times 100}{C_0} \tag{2}$$

3. Results and discussion

From the adsorption tests, it was observed that the smallest mass of material (0.01 g) showed the highest adsorption capacity (22.70 mg g-1) and, consequently, the best percentage removal (90.8 %) of NR after 900 min of reaction. The results of the mass test are shown in Figure 2.

Figure 2: Mass test of NR adsorption onto SB.

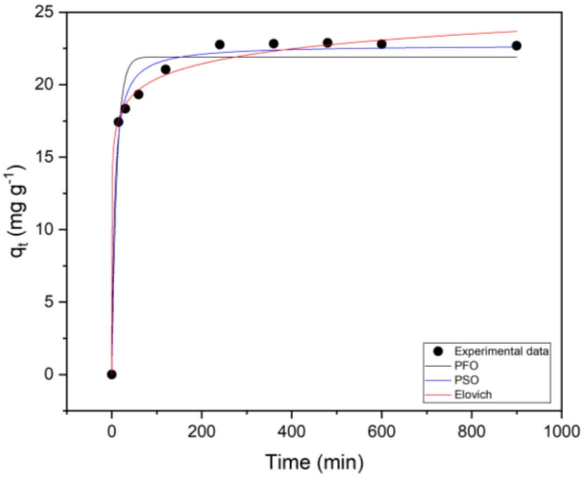


The kinetic study showed that the adsorption capacity (qt) remained constant at around 22.8 mg g-1 at approximately 600 min, suggesting that the equilibrium time had been reached. The kinetic behavior of SB in relation to RN is shown in Figure 3.

Three mathematical models were used, pseudo-first order (PFO), pseudo-second order (PSO) and Elovich, which were fitted to the experimental data. The kinetic parameters are shown in Table 2.

The models showed a good fit to the experimental data, with a coefficient of determination (R^2) of 0.96 for PFO, 0.98 for PSO and 0.99 for Elovich; however, the chi-squared parameter (χ^2), which determines the error, was lower for the Elovich model, with a value of 0.35.

Figure 3: Kinetic studies of NR adsorption onto SB.



The calculated adsorption capacities (qt) were close to the experimental values. These results indicate that the model with the best fit was that of Elovich, which suggests that the adsorption kinetics of neutral red occurred by chemisorption and that the surface of the material is heterogeneous [8].

Table 2. Kinetic parameters of NR adsorption onto SB.

Model	**Parameters**	
Pseudo-first-order $q_t = q_e[1 - e^{-k_1 t}]$	qt (mg g^{-1})	21.92 ± 0.54
	K_1 (h^{-1})	0.09 ± 0.02
	R^2	0.96
	χ^2	2.08
Pseudo-second-order $q_t = \frac{k_2 q_e^2 t}{1 + k_2 q_e t}$	qt (mg g^{-1})	22.74 ± 0.34
	K_2 (h^{-1})	0.007 ± 0.001
	R^2	0.98
	χ^2	0.60
Elovich	a (mg g^{-1} min)	13642.05 ± 17927.09
$q_t = \frac{1}{b}\ln a\,b + \frac{1}{b}\ln t$	b (mg g^{-1})	0.67 ± 0.06
	R^2	0.99
	χ^2	0.35

According to Vo et al. [9], cellulose, hemicellulose and lignin, which contain free carboxylic (-COOH) and hydroxyl (-OH) groups, are able to interact with ionic dyes through hydrogen bonds, n-π or π- π interactions and electrostatic attraction.

In this way, it can be inferred and suggested that the biosorption mechanism involved occurred through interactions between the functional groups of SB and the NR dye. Consequently, the presence of these molecules on the residue surface was effective in removing the pollutant under study.

Thus, this research presents an effective and low-cost alternative for the remediation of wastewater contaminated by cationic dyes. Furthermore, it is suggested that studies of solution pH variation, ionic strength evaluation and isotherms be carried out so that the biosorption mechanism can be further investigated.

4. Conclusion

The proposed study shows that raw sugarcane bagasse was able to remove the neutral red dye from simulated contaminated water, without the need to functionalize the residue.

The adsorption capacity remained constant at 22.8 mg g-1 at approximately 600 min using the lowest SB mass. The kinetic model that best fitted the experimental data was that of Elovich, proposing that the adsorption mechanism occurred by chemisorption.

Future suggestions include more in-depth adsorption tests to better understand the mechanisms of neutral red biosorption using sugarcane bagasse.

Acknowledgements

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific Sciences and Technological Development (CNPQ).

References

[1] FREITAS, Fabiana Paiva de et al. Adsorption of neutral red dye by chitosan and activated carbon composite films. Heliyon, v. 7, n. 7, p. 1-10, jul. 2021.
[2] EBRATKHAHAN, Masoud et al. Removal of Neutral Red Dye via Electro-Fenton Process: a response surface methodology modeling. Electrocatalysis, v. 12, n. 5, p. 579-594, 24 maio 2021.
[3] NAJAFI, Mahnaz et al. Metal-organic and covalent organic frameworks for the remediation of aqueous dye solutions: adsorptive, catalytic and extractive processes. Coordination Chemistry Reviews, v. 454, p. 214332, 2022.
[4] DENG, Lingjuan et al. Using adsorption product of reduced graphite oxide for neutral red as bind-free electrode for solid-state supercapacitor. Materials Science And Engineering: B, v. 278, p. 115649, abr. 2022.
[5] ZHANG, Linye et al. Novel magnetic N-doped biochar derived from sugarcane bagasse and red mud for effective adsorption of tetracycline hydrochloride. Journal of Environmental Chemical Engineering, v. 12, n. 3, p. 113041, jun. 2024.
[6] ZHOU, Yanbo et al. Recent advances for dyes removal using novel adsorbents: a review. Environmental Pollution, v. 252, p. 352-365, 2019.
[7] ALOKIKA et al. Cellulosic and hemicellulosic fractions of sugarcane bagasse: potential, challenges and future perspective. International Journal of Biological Macromolecules, v. 169, p. 564-582, fev. 2021.
[8] QUESADA, Heloise Beatriz et al. Evaluation of novel activated carbons from chichá-do-cerrado (Sterculia striata St. Hil. et Naud) fruit shells on metformin adsorption and treatment of a synthetic mixture. Journal of Environmental Chemical Engineering, v. 9, n. 1, p. 104914, fev. 2021.
[9] VO, Hao Nhien et al. Removal of pararosaniline hydrochloride (basic red 9) from aqueous system with lignocellulose fraction of sugarcane bagasse as adsorbent. Industrial Crops and Products, v. 188, p. 115573, nov. 2022.