International Journal of Biological Macromolecules 284 (2025) 137867

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

journal homepage: www.elsevier.com/locate/ijbiomac

Tailoring of carboxymethyl guar gum hydrogels via gamma irradiation for remarkable removal of cationic and anionic dyes from simulated solutions

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ARTICLE INFO

Keywords:
Guar gum hydrogel
Gamma radiation
Dye removal

ABSTRACT

Green hydrogels were synthesized from carboxymethyl guar gum (CMGG)-polyacrylic acid (PAAc) via gamma irradiation at doses of 10–40 kGy, they were codes as (CMGG/PAAc). FTIR spectroscopy was applied to confirm the chemical transformation of GG into the hydrogel formulations while the ^{1}HNMR was employed to confirm the successful preparation of CMGG. TGA, XRD, and AFM were used to compare the improved formulation to native and CMGG. The investigated hydrogels were then applied comparatively to remove methylene blue (MB) and methyl orange (MO) dyes from aqueous solution under various operating parameters. In addition, the AFM was used comprehensively to address the adsorption process by comparing the surface topographies, height and roughness measurements between the dry and dye-loaded hydrogel. Four adsorption isotherms were investigated in order to go deep through the adsorption mechanism. These are Langmuir Freundlich, Redlich–Peterson and Jovanovich isotherms. Based on the values of R^2 for all the models, it can be assumed that the Langmuir model is best appropriate for the adsorption process and that the dyes were adsorbed onto a homogenous surface. Kinetic tests showed that the pseudo-second-order model best fitted the adsorption process, with R^2 values of 0.9999 for both dyes, confirming chemisorption as the rate-limiting step. The thermodynamic data indicates spontaneous, exothermic adsorption processes, with Gibbs free energy changes (ΔG) for MB ranging from −11.265 to −10.82 kJ/mol and MO from −3.221 to −3.323 kJ/mol. Negative enthalpy changes (ΔH) of −17.892 kJ/mol for MB and − 17.005 for MO show the exothermic nature of adsorption. The data proved effective removal of MB and MO dyes onto CMGG/PAAc hydrogels with better affinity for MB dye, making them excellent wastewater treatment adsorbents.

1. Introduction

Wastewater pollution resulted from different industries such as papermaking, cosmetics, pigments, textiles, and chemical manufacturing has become a pressing environmental issue [1,2]. The release of dyes into wastewater poses a significant threat due to their non-biodegradability, high toxicity, carcinogenic properties, mutagenicity, and other related environmental damages. These dyes, often resistant to conventional wastewater treatment methods, persist in the environment, causing long-term impairment to aquatic ecosystems and human health. Consequently, there is an essence need for effective and sustainable solutions to mitigate the impact of dye-laden industrial effluents. There are several methods employed for removal of dyes from colored effluents, these include oxidative degradation [3] complexation and precipitation [4], biological degradation [5] and photocatalytic degradation [6], adsorption [7]. Among all protocols, adsorption of different sorbent materials has gained excessive attention as a potential route for the removal of dyes and other pollutive materials from wastewater. In this contest, hydrogels are found to be very effective sorbents due to their crosslinked three-dimensional architecture and chemically reactive functional groups, which strongly contribute to their outstanding adsorption capacity [8,9]. Hydrogels can effectively adsorb both cationic dyes, such as methylene blue (MB) [10,11], and anionic dyes, such as methyl orange (MO) [12], Acid Blue 7, Reactive Red 120, and Direct Red 23 [13], crystal violet [14,15]. Other advantages such as their reusability, low cost, availability and ease of application further enhance their suitability for treating dye-contaminated wastewater

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https://doi.org/10.1016/j.ijbiomac.2024.137867
Received 17 August 2024; Received in revised form 29 October 2024; Accepted 17 November 2024
Available online 24 November 2024