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Adsorption process for removing hazardous Congo red dye from aqueous solutions: isotherm, kinetic, and thermodynamic studies

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ABSTRACT

The removal of Congo red dye from aqueous solutions by adsorption reaction onto three distinct adsorbents: graphene oxide (GO), graphene oxide-grafted-3,3′-diaminobenzidine (GO/DAB), and GO/DAB-grafted-ethylenediaminetetraacetic acid (GO/DAB/EDTA) was investigated in batch experiments. The study of the effects of pH and contacting time on adsorption systems is the first step in optimizing them. The results revealed that depending on the type of adsorbent, the optimum pH values and periods differed. The Congo red (CR) dye adsorptions onto the investigated adsorbents GO, GO/DAB, and GO/DAB/EDTA required pH (3.0, 7.0, and 5.0, respectively) and time (60, 30, and 45 min). The fundamental adsorption properties of the dye were evaluated using adsorption equilibrium isotherms, namely the Langmuir, Freundlich, and Dubinin–Radushkevich models. The maximum adsorption values (q_{max}) were calculated using the Langmuir isotherm results, and they were 1,250; 1,428.5 and 1,438.1 mg/g for the adsorption of CR dye onto adsorbents GO, GO/DAB, and GO/DAB/EDTA, respectively, and these results proved the preference for prepared GO-derivatives over GO. The kinetic models, namely pseudo-first-order and pseudo-second-order, were employed to understand the mechanism of the adsorption process, and they fitted very well with the pseudo-second-order kinetic model, which relies on the assumption that chemisorption may be the rate-limiting step. This study reveals that the presence of functional groups and active sites on the studied adsorbent contributed to its high affinity for CR dye adsorption. As a result, they can be used as efficient and cost-effective dye adsorbents in industrial effluent. Thermodynamic parameters including enthalpy $\Delta H°$, entropy $\Delta S°$, free energy $\Delta G°$, and activation energy E_a of the adsorption process were calculated and used to interpret the results, which revealed that the adsorption systems were a spontaneous and endothermic process for GO and its composites. Also, low activation energy values (E_a < 40 kJ/mol) were characteristics of the physisorption mechanism and diffusion-controlled process.

Keywords: Congo red; Adsorption; Hazardous; Isotherm; Desorption; Pseudo-second-order; Activation energy

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