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Adsorption of anionic dye Direct Red 23 onto magnetic multi-walled carbon nanotubes-Fe_3C nanocomposite: Kinetics, equilibrium and thermodynamics

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HIGHLIGHTS

- ▶ Magnetic nanocomposite was used as an adsorbent for the removal of Direct Red 23.
- ▶ Nanocomposite can be easily separated from the water by external magnetic field.
- ▶ Adsorption of Direct Red 23 onto nanocomposite was favored at low pH.
- ▶ Adsorption of Direct Red 23 onto nanocomposite was endothermic in nature.

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ABSTRACT

Magnetic multi-walled carbon nanotubes-Fe_3C nanocomposite (MMWCNTs-ICN) was synthesized by chemical vapor deposition (CVD) process and was used as an adsorbent for the removal of anionic dye Direct Red 23 (DR23) from aqueous solution. The effects of various parameters such as initial DR23 concentration (9–54 mg L^{-1}), pH solution (3.7–11.1) and temperature (20–60 °C) were investigated. The adsorbent was characterized with using several methods such as XRD, HRTEM, EDX, FTIR, BET and particle size distribution by laser diffraction. The experimental data were analyzed by the Langmuir and Freundlich models of adsorption. Equilibrium data fitted well with the Freundlich model. Kinetic adsorption data were analysed using the Lagergren pseudo-first-order kinetic model, the pseudo-second-order model and the intraparticle diffusion model. The regression results showed that the adsorption kinetics was more accurately represented by pseudo-second-order model. Thermodynamics parameters, $\Delta G°$, $\Delta H°$ and $\Delta S°$, were calculated. All $\Delta G°$ values were negative. The values of enthalpy ($\Delta H°$) and entropy ($\Delta S°$) were 12.6 kJ mol^{-1} and 61.7 J mol^{-1} K^{-1}, respectively, indicating that adsorption of DR23 onto MMWCNTs-ICN was spontaneous and endothermic in nature.

1. Introduction

Carbon nanotubes (CNTs) discovered in the early 1990s by Iijima [1], have attracted great attention in multidisciplinary areas due to their unique physical, chemical and mechanical properties. CNTs are seamless cylinders formed by the honeycomb lattice of a single layer of crystalline graphite, called a graphene sheet [2]. Depending on the number of graphene sheets, CNTs are divided into two types, singlewalled carbon nanotubes (SWCNTs) and multiwalled carbon nanotubes (MWCNTs). SWCNTs consist of single layer graphene sheet and MWCNTs consist of several layers of graphene sheets.

Many applications of CNTs based on their unique properties have been proposed, such as hydrogen storage [3], composite materials [4] or nano-electronics [5]. In recent years, CNTs have also been used as adsorbents to remove various types of organic and inorganic pollutants from water. Due to their large specific surface area, small size, and hollow and layered structures, CNTs have been used as adsorbents for the removal of trihalomethanes [6], xylene [7], 1,2-dichlorobenzene [8], dioxin [9], zinc(II) [10], fluoride [11], lead(II) [12], chromium(VI) [13] and mercury(II) [14].

One of the most dangerous pollutants in water are synthetic dyes. They are used extensively in paper, textile, food, leather, cosmetics, plastic and other industries. Dyes represent an undesirable class of compounds requiring special treatment, due to the fact that the presence of these compounds in water bodies reduces light penetration, precluding photosynthesis of the aqueous flora [15]. Additionally, many organic dyes may contain chemicals that are carcinogenic and toxic to human beings, microorganisms and fish species. Therefore, as a new promising adsorbent, CNTs have also been used for the removal of dyes from aqueous solution [16–27].

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