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Surface modification of magnetic nanoparticle and dye removal from ternary systems

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ABSTRACT

The surface of magnetic zinc ferrite nanoparticle (ZFN) was modified using sodium dodecyl sulfate (SDS). Dye removal ability of ZFN–SDS was investigated from ternary systems. The characteristics of ZFN–SDS were studied using FTIR, SEM, TEM and XRD. Basic Blue 41 (BB41), Basic Red 18 (BR18) and Basic Violet 16 (BV16) were used. The effect of operational parameters (adsorbent dosage and initial dye concentration) on dye removal was evaluated. The maximum adsorption capacity (Q_0) was 42, 61 and 16 mg/g for BB41, BR18 and BV16, respectively. Dye adsorption on ZFN–SDS followed pseudo-second order kinetics and Langmuir isotherm model.

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Introduction

Organic pollutants such as dyes and pesticides are removed from wastewater using different methods [1–11]. Dye removal from colored aqueous media using solid materials is interested due to the transferring of specific substances from solution onto their surfaces. Some disadvantages of traditional materials as adsorbents are poor separation ability and relatively limited adsorption capacity for dyes. Thus researchers interest to focus on modified adsorbents.

The application of magnetic compounds is an emerging field of water and wastewater treatment [10,12–14]. The magnetic materials as adsorbents have opened a new field in separation technology. The magnetic materials could be separated based on their nanostructures because the ease of direction of magnetization would vary depending on the ordering of atoms in the magnetic structure [12,15]. The application of a magnetic field induces the magnetization of the material and thus makes the use of a magnetic force possible, but when the magnetic field is cut of, the magnetization immediately decreases to zero. It is important for the release of particles after adsorption of the waste [13,16].

The main disadvantage of some magnetic nanoparticles is low potential pollutant removal ability. To conquest this disadvantage, the surface of magnetic nanoparticles was modified using several materials such as surfactants. The surface properties of nanoparticles can be modified with a surfactant. This is favored by van der Waals interaction between surfactant and the adsorbent.

Several magnetic materials have been used to remove dyes from aqueous solution [10,17–20]. Nanoparticles have low adsorption capacity of dyes. Thus researchers interest to modify the surface of nanoparticle. The ammonium-functionalized silica nanoparticle as a new adsorbent was used to remove methyl orange from aqueous solution [21]. The modified Fe_3O_4 magnetic nanoparticle using ionic liquid was studied to remove of reactive red-120 and 4-(2-pyridylazo) resorcinol from aqueous samples [22]. Zinc ferrite nanoparticle (ZFN) was synthesized in previous published paper and used as photocatalyst [23]. The literature review showed that surface modified zinc ferrite nanoparticle (ZFN–SDS) by sodium dodecyl sulfate (SDS) was not used to remove dyes from ternary systems. In this paper, zinc ferrite nanoparticle was synthesized and its surface was modified using SDS. The modified nanoparticle was used an adsorbent. Dyes were removed from single and ternary systems using ZFN–SDS. Fourier transform infrared (FTIR), scanning electron microscopy

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(SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD) were used to characterize ZFN–SDS. Three basic dyes were used. The dye adsorption isotherm and kinetic and effect of operational parameters (adsorbent dosage and initial dye concentration) on dye removal was evaluated.

Experimental

Chemicals

Basic Blue 41 (BB41), Basic Red 18 (BR18) and Basic Violet 16 (BV16) were used. The chemical structure of dyes was shown in Fig. 1. All other chemicals were of analytical grade and obtained from Merck.

Synthesis of ZFN and ZFN–SDS

Synthesis of ZFN
4.90 g zinc nitrate (297 g/mol) and 13.4 g iron nitrate was dissolved in 50 mL distilled water and added to aqueous mixed solution 4.2 g NaOH in 70 mL distilled water and 3 mL ethylene diamine (EG). This solution was heated at 90 °C for 1 h to achieve complete chelation. The powder was calcined on alumina crucible at 500 °C for 1 h, with a heating rate of 10 °C/min [23].

Synthesis of ZFN–SDS
SDS (0.4 g) was added to solution containing 10 mL acetone, 125 mL distilled water and 1 g ZFN. The mixture was stirred in a mixer for 1 h. The organo-modified ZFN was separated from the mixture by magnetic force and then was washed with distilled water until free of salts.

Physicochemical characterization

FTIR spectrum (Perkin-Elmer Spectrophotometer Spectrum One) in the range 4000–450 cm^{-1} was studied. The morphological structure of the material was examined by SEM using LEO 1455VP scanning microscope. Crystallization behavior was identified by XRD model Siemens D-5000 diffractometer with Cu $K\alpha$ radiation (λ = 1.5406 Å) at room temperature.

Adsorption procedure

The dye adsorption was done by mixing of adsorbent in 250 mL of a dye solution (50 mg/L) for 60 min. The solution samples were taken at certain time intervals (0, 2.5, 5, 7.5, 10, 15, 20, 30, 40, 50 and 60 min.) and adsorbent particles were separated by magnetic force. The change on the absorbance of all solution samples were monitored and determined at certain time intervals during the adsorption process. At the end of the adsorption experiments, the dye concentration was determined.

UV-Vis Perkin-Elmer Lambda 25 spectrophotometer was employed for absorbance measurements of samples. The maximum wavelength (λ_{max}) used for determination of residual concentration of BB41, BR18 and BV16 in supernatant solution using UV–VIS spectrophotometer were 605 nm, 488 nm and 545 nm, respectively.

The effect of operational parameters (adsorbent dosage and initial dye concentration) on dye removal was investigated.

The effect of adsorbent dosage (0.1–0.4 g) on dye removal was investigated by contacting 250 mL of dye solution with initial dye concentration of 50 mg/L at room temperature (25 °C) for 60 min.

The effect of initial dye concentration (50–200 mg/L) on dye removal was investigated by contacting 250 mL of dye solution with ZFN–SDS at room temperature (25 °C) for 60 min.

Dye concentrations were calculated as follows: for a ternary system of components A, B and C that were measured at wavelengths of λ_1, λ_2, and λ_3, respectively, to give optical densities of d_1, d_2, and d_3 [24,25]:

$$C_A = \frac{d_1 X + d_2 Y + d_3 Z}{k_{A1}X + k_{A2}Y + k_{A3}Z}, \quad (X = k_{B3}k_{C2} - k_{B2}k_{C3}; \ Y = k_{B1}k_{C3} - k_{B3}k_{C1}; \ Z = k_{B2}k_{C1} - k_{B1}k_{C2}) \tag{1}$$

$$C_B = \frac{d_1 X' + d_2 Y' + d_3 Z'}{k_{B1}X' + k_{B2}Y' + k_{B3}Z'} \quad (X' = k_{A2}k_{C3} - k_{A3}k_{C2}; \ Y' = k_{A3}k_{C1} - k_{A1}k_{C3}; \ Z' = k_{A1}k_{C2} - k_{A2}k_{C1}) \tag{2}$$

$$C_C = \frac{d_1 X'' + d_2 Y'' + d_3 Z''}{k_{B1}X'' + k_{B2}Y'' + k_{B3}Z''} \quad (X'' = k_{A2}k_{B3} - k_{A3}k_{B2}; \ Y'' = k_{A3}k_{B1} - k_{A1}k_{B3}; \ Z'' = k_{A1}k_{B2} - k_{A2}k_{B1}) \tag{3}$$

where k_{A1}, k_{B1}, k_{C1}, k_{A2}, k_{B2}, k_{C2}, k_{A3}, k_{B3}, and k_{C3} are the calibration constants for components A, B, and C at the three wavelengths λ_1, λ_2, and λ_3, respectively.

Results and discussion

Characterization of ZFN–SDS

The FT-IR spectrum of ZFN and ZFN–SDS was shown in Fig. 2. ZFN has two peaks at 3450 cm^{-1} and 500–600 cm^{-1} which indicate O–H stretching vibration and metal-oxygen vibration, respectively. The FTIR spectrum of the ZFN–SDS displays a number of characteristic bands (Fig. 2). The bands at 3415, 2919, 2851, 1636 and 1435 cm^{-1} corresponds to O–H stretching vibration, C–H asymmetrical stretching, C–H symmetrical stretching, the bending vibration of absorbed molecular water and the bending vibration of C–H, respectively. The peaks at 1384–874 cm^{-1} are due to asymmetric and symmetric stretching and bending of the SO$_4$ anion or CH$_3$ bending, CH$_2$ bending, and C–C stretching modes of SDS [26].
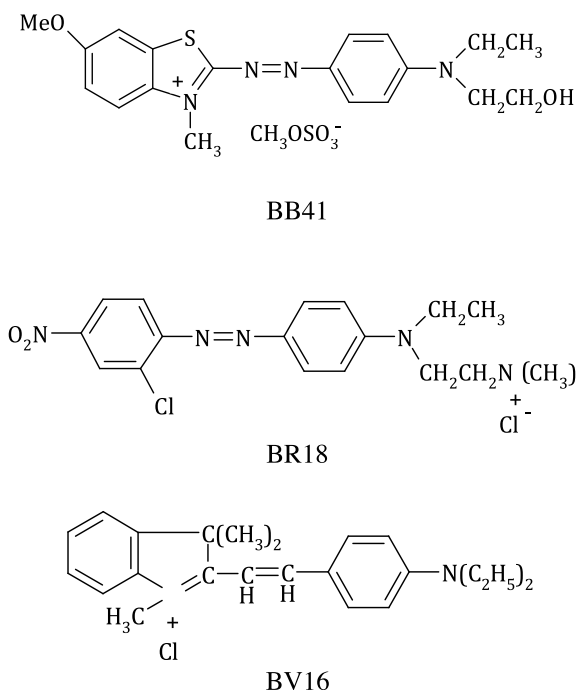

Fig. 1. The chemical structure of dyes.