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Functionalized agricultural biomass as a low-cost adsorbent: Utilization of rice straw incorporated with amine groups for the adsorption of Cr(VI) and Ni(II) from single and binary systems

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ABSTRACT

The adsorption of Cr(VI) and Ni(II) applying amine-functionalized modified rice straw (MRS) as an adsorbent in single and binary systems was investigated. The MRS was characterized by Fourier transform infrared spectroscopy (FTIR), Thermo-gravimetric Analysis (TG), Brunauer–Emmett–Teller (BET) analysis, Scanning Electron Microscope (SEM) and the Energy Dispersive Spectrometer (EDS) analysis. The adsorption study was conducted systematically by varying adsorbent dosage, initial pH value, temperature and initial metal ion concentration. The results showed that the maximum adsorption capacity for Cr(VI) was 15.82 mg/g with MRS dosage 10 g/L at pH 2.0, temperature 318 K and initial metal ion concentration 200 mg/L, and 3.95 mg/g for Ni(II) at pH 7.0, temperature 318 K and initial metal ion concentration 80 mg/L with MRS dosage 10 g/L, respectively. The adsorption data were suitable for Langmuir isotherm model better both in single and binary systems. The pseudo-second-order model could better describe the adsorption process in single and binary systems. In binary systems, the existence of Ni(II) hindered the adsorption of Cr(VI) but the removal of Ni(II) was enhanced with the existence of Cr(VI) ions. Thermodynamic constant values ($\Delta G^0 < 0$, $\Delta H^0 > 0$, $\Delta S^0 > 0$) illustrated that the adsorption of Cr(VI) and Ni(II) onto MRS were spontaneous and endothermic.

1. Introduction

In recent years, with the rapid development of modern industry, the discharge of metals such as nickel and chromium are ecological threats, even at low concentration [1–4]. Cr(VI) and Ni(II) ions are widely used in leather tanning, electroplating, cement manufacturing and dye industries [5,6], the concentration of which can reach hundreds of milligrams per liter in high-concentration electroplating wastewater [5]. Therefore, environmental regulations require the treatment of wastewater to remove and recover heavy metals [7].

Various methods for heavy metal removal have been proposed, demonstrated and applied, such as chemical precipitation [8], membrane filtration [9] and ion exchange [10–12]. Compared with treatment methods listed above, adsorption is considered as an efficient method for the removal of heavy metals from wastewater with several advantages like no chemical sludge, easy to operate [13] and the process appears to be inexpensive [13–15].

Rice straw is comprised of cellulose, hemicellulose and lignin that can adsorb heavy metals in aqueous solutions validly [6]. Hence the adsorption of heavy metal ions with waste agricultural materials could provide a novel treatment of both crop residues and heavy metal pollution.

In several previous reports, many authors have documented the use of rice straw for the adsorption of heavy metals [16–18]. Whereas, a lot of previous researchers simply modified rice straw by acid or alkali washing, which just improved the adsorption capacity inconspicuously. The amine-functionalized modified rice straw, however, with the incorporation of amine groups, showed the prominent ability in the removal of metal ions [19,20] due to the fact that amine groups are easily to be protonated in acid environment and the metal ions could be adsorbed onto the adsorbent

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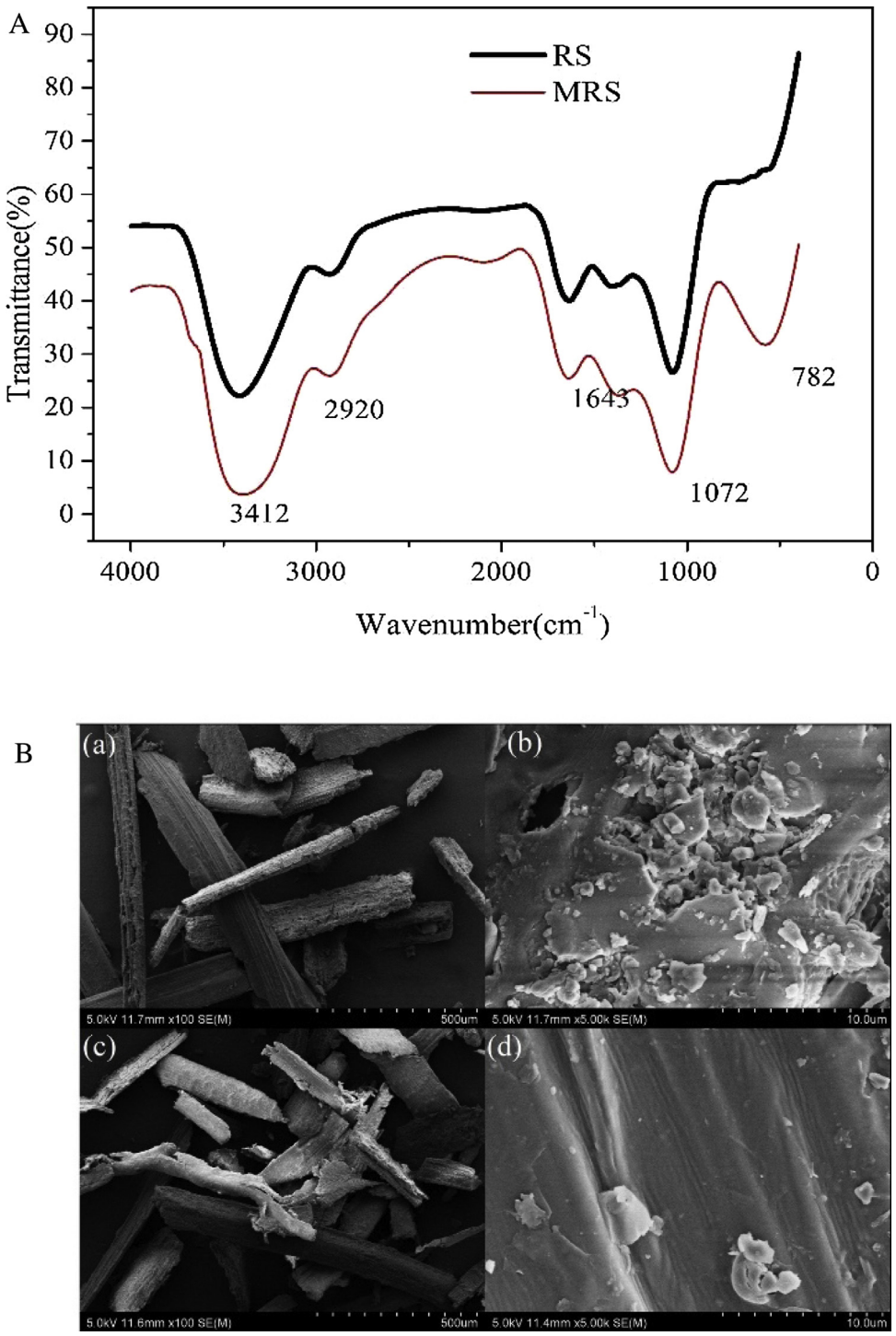

Fig. 1. FTIR spectra of RS and MRS (A) and SEM photographs of RS (a, b) and MRS (c, d) (B).

by electrostatic and ion exchange [21,22], which could improve the adsorption efficiency. Furthermore, industrial wastewater usually contains several species of metals, and so the metallic sorption behaviors become more intricate [23]. Thus, a sorption study for multiple metals is realistic.

The purpose of this work is to investigate the capability of amine-functionalized modified rice straw (MRS) for the removal of Cr(VI) and Ni(II) from single and binary component systems. The adsorbent was characterized by Fourier transform infrared spectra (FTIR), Thermo-gravimetric Analysis (TG), Brunauer–Emmett–Teller (BET) and Scanning Electron Microscope (SEM). The kinetic and thermodynamic parameters were calculated and the equilibrium data were fitted to some isotherm models to determine the adsorption mechanism.

2. Materials and methods

2.1. Preparation of modified rice straw

Rice straw (RS) was collected from a cultivated area in Jiangsu province, China. RS was washed with distilled water and then dried for 24 h at 373 K. Next, the oven-dried rice straw was crushed,