Characterization of modified mineral waste material adsorbent as affected by thermal treatment for optimizing its adsorption of lead and methyl orange

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ABSTRACT

Thermal treatment is one of the most common processes in mineral modification, and this process has been applied to the modification of mineral waste material to improve its adsorption ability of methyl orange (MO) and lead (Pb) in this study. The properties of modified mineral waste material (MMWM) before and after thermal modification were characterized by using the Brunauer–Emmett–Teller (BET) N₂ adsorption/desorption measurement, field emission scanning electron microscope (FESEM) coupled with energy-dispersive X-ray (EDX), X-ray diffraction (XRD), and Fourier transform infrared spectroscopy (FTIR). Phase transformation was investigated related to the change in surface morphology and dehydroxylation that occurred in MMWM samples during the process of thermal treatment. To study adsorption performances of Pb and MO onto the newly modified MMWM, several experiments were carried out under different adsorption conditions and the results were determined using inductively coupled plasma optical emission spectrometry (ICP-OES) and UV-Vis spectrophotometry. The thermally treated MMWM samples showed morphological transformation and an increasing trend in BET specific surface area (SSA) up to 500 °C followed by a decreasing trend till 1000 °C. Thermal modification of MMWM successfully improved Pb adsorption from 349 to 515 mg/g, corresponding to the MMWM modified at 600 °C, and the methyl orange (MO) adsorption from 68 to 87.6 mg/g at 400 °C. The adsorptions of Pb and MO were mainly chemisorption and monolayer coverage, as the pseudo-second-order model and the Langmuir equation displayed good correlations for Pb and MO adsorption data.

Keywords: Adsorption, dehydroxylation, lead (Pb), methyl orange (MO), modified mineral waste material (MMWM)

INTRODUCTION

The modified mineral waste material (MMWM) is a mixed clay mineral type of adsorbent that was originally derived from industrial mineral waste after physical and chemical modifications (Jiang et al. 2013a). It can be used as a low-cost, environmentally safe adsorbent and found to have strong adsorption abilities (Jiang et al. 2013b). Consisting primarily of smectite and illite, MMWM shows great ability in adsorbing pollutants from water, soil, and air that have been applied in our previous experiments for removing environmental pollutants (Jiang et al. 2014; Lu et al. 2016). These investigations have confirmed that the MMWM has better adsorption abilities of heavy metals [lead (Pb), copper (Cu), and cadmium (Cd)] in solution than activated carbon (AC) (Lu et al. 2016). MMWM was also found to have the ability to adsorb organic compounds from wastewater such as organic phosphate (Jiang et al. 2014). The adsorptive efficiency of some organic pollutants is found to be even better than AC.

As one of the main components in MMWM, the smectite group of clays (e.g., montmorillonite) is normally abundant and has extraordinary properties that make it a compelling and reasonable precedent for a low cost and effective adsorbent (Rathnayake et al. 2017). Smectite is comprised of several clay minerals consisting of tetrahedral-octahedral-tetrahedral (t-o-t) layers of both dioctahedral and trioctahedral types (Hurlbut and Klein 1977; Bhattacharyya and Gupta 2008). Similar to smectite (e.g., montmorillonite), illite is another kind of clay mineral in MMWM. It can be defined as the mineral occurring in the clay fraction with Al–K and is non-expanding, di-octahedral with mica-type properties, and it is a mineral that is commonly used in the traditional ceramic industry and can be applied in the removal of heavy metals in solution (Sordori and Eberl 1984; Ozdes et al. 2011; Csáki et al. 2017; Húlan et al. 2017). On the other hand, the swelling properties of the 2:1 layer silicates (e.g., montmorillonite) result in an increased water and contaminants retention ability, which depends on the interlayer spacing, the charge of layer, hydration energy, chemical potential, and relative humidity (Tambach et al. 2004; Fonseca et al. 2017).

Investigations pertaining to the use of mineral-related adsorbents have a long history, and the high adsorption capabilities of clay minerals are the result of the net negative charges on the lattice of minerals. These negative charges will be neutralized by the adsorption of positively charged contaminants, providing clay adsorbents the ability to attract and hold cations such as heavy metals (Belzunces et al. 2017).

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