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ScienceDirect
Journal of Taibah University for Science 9 (2015) 465–476
Journal of Taibah University for Science
www.elsevier.com/locate/jtusci

Physicochemical analysis of automobile effluent before and after treatment with an alkaline-activated montmorillonite

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Available online 4 December 2014

Abstract

Effluents obtained from six industries were analysed for physicochemical properties. An alkaline-modified montmorillonite was used to remove heavy metals from automobile effluent. The effects of effluent pH, adsorbent dose, adsorbent particle size and contact time on adsorption were determined. Langmuir, Freundlich, Temkin and Dubinin–Radushkevich models were used to analyse equilibrium isotherms. Kinetics was analysed by the pseudo-first-order, pseudo-second-order, intra-particle diffusion and film diffusion rate equations. Thermodynamic parameters including changes in free energy, entropy and enthalpy were calculated. The alkaline-modified montmorillonite was effective for treatment of effluent contaminated with heavy metals.

Keywords: Alkaline modification; Montmorillonite; Effluent; Treatment; Heavy metals

1. Introduction

Pollution of the environment by industrial effluent discharges containing heavy metals is a major problem. Automobile, battery, pharmaceutical, mining, electroplating, soap and detergents, textile, paint, breweries and electroplating industries often produce effluents containing heavy metals [1]. When the metals reach water bodies, they pose a serious threat to aquatic life, plants and humans due to their toxicity, non-biodegradability and accumulation in the food chain [2]. The determination of heavy metal concentrations in industrial effluents and subsequent treatment are therefore necessary for maintaining environmental quality. Conventional methods for removing heavy metals and other pollutants from effluents include evaporation, filtration, precipitation, oxidation–reduction, electrochemical treatment, ion exchange, solvent extraction and activated carbon adsorption [3]. All these methods have disadvantages, such as high cost, poor efficiency, secondary contamination and inapplicability to a wide range of pollutants [4]. Adsorption has been found to be the most effective method, and many low-cost materials, such as fertilizer waste, biomass, tea waste, microorganisms, charcoal, ash, laterite, red mud and clay, have been used as adsorbents for effluent treatment [5].

Clay minerals are effective adsorbents, and the alkaline modification further increases their adsorption potential [6–8]. In our previous study [9], we found that alkaline modification of a laboratory solution of

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Peer review under responsibility of Taibah University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jtusci.2014.10.005
1658-3655

local montmorillonite enhanced its adsorption for heavy metals. The study reported here is a practical extension, in which the heavy metal concentration of six industrial effluents was determined before and after treatment with alkaline-modified montmorillonite. The laboratory solution contained only the added metal ions, whereas industrial effluents contain other contaminants; furthermore, other heavy metals may compete for active sites and thus affect adsorption. The effects of various experimental factors, such as pH, adsorbent dose, particle size and contact time, on adsorption were investigated, and equilibrium, kinetics and thermodynamics analysis were also performed.

2. Materials and methods

2.1. Characterization and adsorption

The montmorillonite clay was obtained from Ugwuoba in the Oji River local government area of Enugu State, Nigeria. The clay was processed and modified as described previously [9] to obtain alkaline-modified montmorillonite. The Fourier transform infrared spectra were determined on a Shimadzu FT-IR 8400s model.

Industrial effluents were obtained from the discharge outlets of automobile, paint, drug, soap and detergent, brewery and food industries (Innoson, Abatex, Juhel, Rewgee, Nigerian Breweries and BONS Foods, respectively). All the industries are located in Enugu State except for Innoson, which is in Nnewi, Anambra State, Nigeria. Samples were collected by the method described by Pearson et al. [10]. The physicochemical characteristics of the effluent were determined by standard methods [11] with analytical grade chemicals obtained from Sigma-Aldrich. An atomic absorption spectrophotometer (Buck Scientific, model 210VGP) was used to determine the heavy metal concentrations in the effluents.

Batch adsorption was used to remove heavy metals from automobile effluent, as it had a higher concentration of heavy metals than the other effluents. Optimum adsorption conditions (pH 6.5, adsorbent particle size 100 μm, adsorbent dose 0.1 g and contact time 180 min) were used for contacting 0.1 g of alkaline-modified montmorillonite with 50 mL of effluent in a 100-mL plastic bottle. The effect of the initial pH of the effluent on adsorption was studied by varying the pH from 2 to 8 by dropwise addition of 0.1 mol/L NaOH or HCl. The influence of adsorbent dose was studied in the range 0.1–0.5 g at temperatures of 300, 313 and 323 K in a thermostated water bath. The effect of particle sizes of 100–500 μm was studied, and contact time was studied in the range 10–300 min. At the end of each contact time, the solution was filtered, and the residual heavy metal concentration in the filtrate was determined by atomic absorption spectrophotometry. The adsorption uptake capacity (q_e, mg/g) of the modified montmorillonite was calculated from the mass balance equation:

$$q_e = \frac{v(C_o - C_e)}{m}, \quad (1)$$

where C_o (mg/L) and C_e (mg/L) are the initial and equilibrium concentrations of the metal ions in the effluent, v (L) is the volume of the effluent used, and m (g) is the mass of montmorillonite used for adsorption.

2.2. Equilibrium isotherms

Equilibrium adsorption isotherms are important in describing how metal ions interact with adsorbents and are useful in the design of adsorption systems. Equilibrium isotherms were analysed in the Langmuir, Freundlich, Temkin and Dubinin–Radushkevich (D–R) isotherm models.

The Langmuir isotherm describes monolayer adsorption onto an adsorbent containing a finite number of identical binding sites. The linear form of the equation is given as [12]:

$$\frac{C_e}{q_e} = \frac{1}{q_L K_L} + \frac{C_e}{q_L}, \quad (2)$$

where q_e (mg/g) represents the monolayer adsorption capacity and K_L (L/mg) is a constant related to the energy of adsorption.

The Freundlich isotherm describes multilayer adsorption onto a heterogeneous surface of the adsorbent. The linear form of the Freundlich equation is given as [13]:

$$\log q_e = \log K_F + \left[\frac{1}{n}\right] \log C_e, \quad (3)$$

where K_F (L/g) and n are the Freundlich constants for the adsorption capacity and intensity, respectively.

The Temkin isotherm is based on the assumption that the free energy of sorption is a function of the surface coverage. The linear form is written as [14]:

$$q_e = B \ln A + B \ln C_e, \quad (4)$$

where B (mg/g) is the heat of adsorption and A (L/mg) is the equilibrium binding constant.

The D–R isotherm, which does not assume a homogeneous surface or a constant adsorption potential, was