Journal of Environmental Chemical Engineering 3 (2015) 515–522

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece

Efficient adsorption behavior of phosphate on La-modified tourmaline

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ARTICLE INFO

Article history:
Received 10 October 2014
Accepted 23 January 2015
Available online 29 January 2015

Keywords:
La-modified tourmaline
Phosphate
Adsorption
Water purification

ABSTRACT

Natural mineral tourmaline is an intelligent material with a great potential application for water purification. In this study, tourmaline was modified by La(III) via a simple ion exchange process for high efficient phosphate adsorption. EDX analysis demonstrated the atomic ratio of La(III) in the La-modified tourmaline was 4.6%. SEM analysis indicated that the exhausted adsorbent particles aggregated seriously after phosphate adsorption, becoming more compact. Concurrently, the surface area of La-modified tourmaline increased from 2.19 m^2/g (raw tourmaline) to 15.59 m^2/g after immobilization of La(III). Efficient phosphate adsorption was achieved by the modified sorbent in a wide pH range, even in alkaline solution. Over 90.0% of phosphate adsorption occurred within the initial 15 min, revealing that it was the fast adsorption process, which is beneficial for practical water purification. Pseudo-second-order kinetic model was proved to fit the kinetic data, which indicates phosphate adsorption might be a chemical sorption. The maximal adsorption capacity for phosphate was 108.7 mg/g at 298 K and neutral pH solution, which is higher than those of most other sorbents reported so far. Isotherm and thermodynamic analysis indicated that phosphate adsorption was spontaneous and exothermic. The prepared sorbent proved to be capable of controlling the solution pH to near neutral pH conditions.

Introduction

Phosphate pollution is evidently originated from anthropogenic activities such as industrial development, agricultural production and population explosion. Though phosphate is required by biomass of organisms, excessive introduction of phosphate into water bodies such as lakes and estuaries could lead to an abnormal growth of aquatic plants, which is considered as eutrophication [1]. Eutrophication process is naturally controlled by phosphate and nitrogen bioavailability. A number of consequences such as reduction of dissolved oxygen, death of fish and proliferation of aquatic weeds and algae can be caused by eutrophication, which compromises water potability and endanger public health [2,3]. As a result, the intake of excess phosphate into natural water bodies should be restricted strictly according to more and more stringent effluent standards. Hence, it is critically necessary to develop efficient technologies to remove excessive phosphate from wastewater before flowing into water environment.

Currently, a number of techniques such as adsorption [4], physicochemical precipitation [5], biological treatment [6], membrane technology [7] and ion exchange [8] have been employed for phosphate removal. Considering the cost and efficiency, adsorption is considered as one of the most applicable technologies as it is convenient, reliable and cost-effective. Adsorbents such as aluminum hydroxide [9], zeolite [10], fly ash [11], orange waste [12] and iron-related chemicals [4,13] were tried for the adsorptive removal of phosphate. These sorbents mainly consists of natural minerals, industrial byproducts, agricultural wastes and synthetic materials. Recent study showed composite adsorbents exhibited excellent performance as they could combine the properties and advantages of each of their components [14]. Among these sorbents, La(III)-related sorbents have attracted wide attention due to their high efficiency and adsorption capacity. Xie et al. prepared lanthanum hydroxide by neutralization of lanthanum chloride solution with waste alkaline solution, and the maximal adsorption capacity for phosphate reached 107.53 mg/g [15]. However, the sorbent preparation process was very complicated and time consuming. Kuroki et al. prepared La(III)-modified bentonite via a simple ion exchange process, but the maximum phosphate sorption capacity was only 14.0 mg/g [16]. Hence, it is high desirable to fabricate a composite La(III)-related sorbent with an excellent adsorption capability via a simple approach.

Natural mineral tourmaline is a type of intelligent and functional ecological material used for environmental protection.

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http://dx.doi.org/10.1016/j.jece.2015.01.010
2213-3437/

It is a kind of complex borosilicate mineral belonging to the trigonal space group [17]. The important feature of tourmaline is the generation of spontaneous and permanent poles which can produce an electric dipole. It is capable of radiating far infrared energy, permanently releasing negative ions, producing an electric field and releasing rare microelements [18]. Meanwhile, the solution pH in the presence of tourmaline can be automatically controlled to near neutral pH [19]. Nevertheless, it is scarcely reported on the adsorptive removal of phosphate by tourmaline and tourmaline-related sorbent.

In this research, a novel sorbent La(III)-modified tourmaline was tentatively prepared using a simple ion exchange process, and used for efficient phosphate adsorption. To understand the adsorptive behavior of phosphate on the sorbent, the effect of solution pH, adsorption kinetics and adsorption isotherms were investigated in details. Thermodynamic and FTIR analysis was further carried out to study the adsorption mechanism. The phosphate adsorption capacity of the modified sorbent was also compared with other sorbents reported in literature.

Materials and methods

Materials and apparatus

Anhydrous potassium dihydrogen orthophosphate (KH_2PO_4) were guaranteed grade and other reagents were of analytical

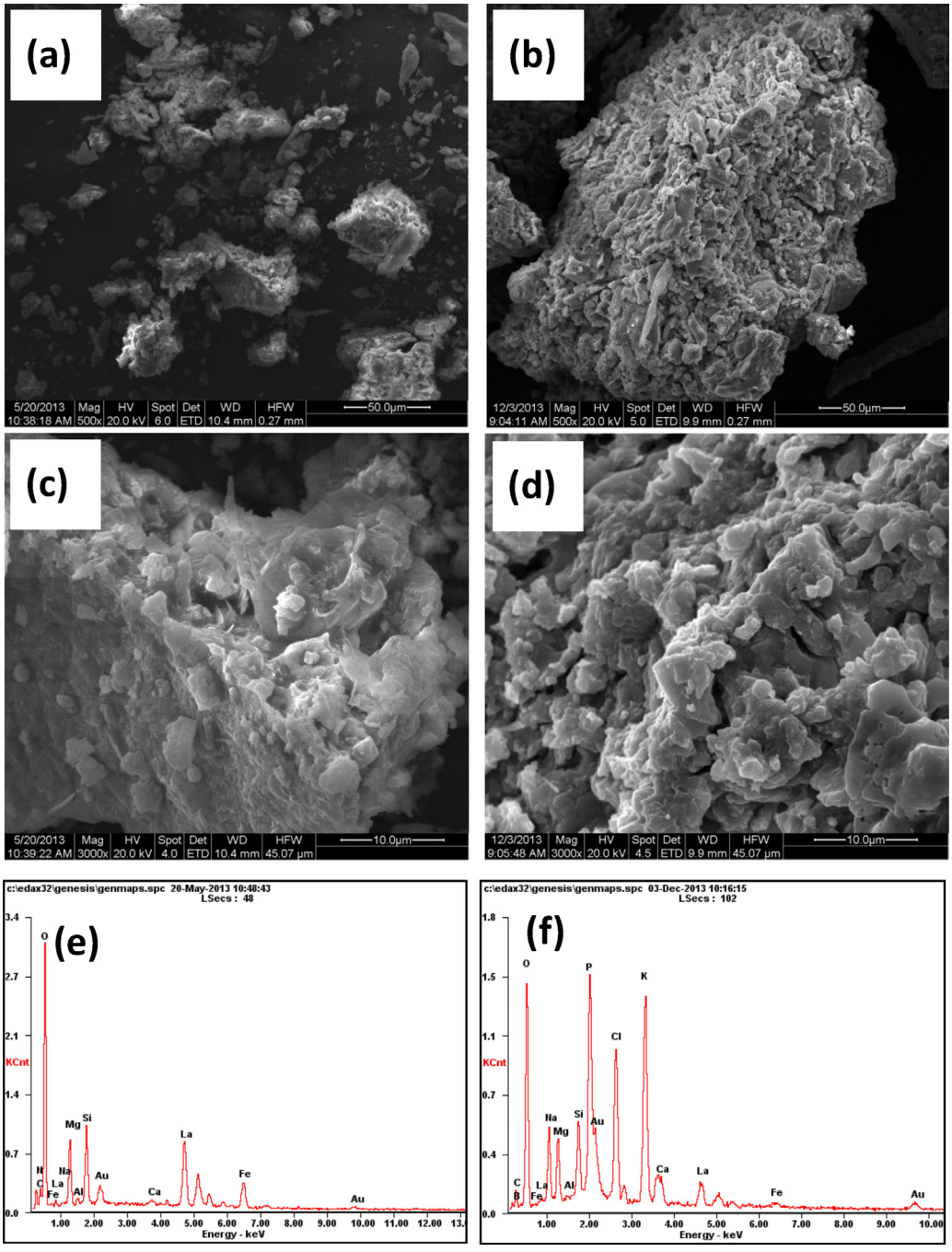

Fig. 1. SEM micrographs and EDX surface analysis of La-modified tourmaline before (a,c,e) and after phosphate adsorption (b,d,f).