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Short communication

Phosphorus removal from wastewater by ionic exchange using a surface-modified Al alloy filter

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ABSTRACT

In this study, a cost-effective and eco-friendly route for removal of phosphate in wastewater was demonstrated using an Al alloy foam filter with a mesoporous aluminum hydroxide ($Al(OH)_3$) film. The mesoporous $Al(OH)_3$ film on which the ion exchange and adsorption of phosphate occur was generated using a simple alkali surface modification process. For higher phosphate removal by the surface-modified Al alloy foam filter, the number of filters was increased up to 20, which achieved 90% phosphate removal within a very short contact time. As a recycling process, a second alkali surface modification was applied to the used filter after phosphate adsorption. It clearly indicated that the used filter can be recycled via a second alkali surface modification due to the ion exchange mechanism. It was shown that an alkali surface-modified Al alloy foam filter is a powerful candidate for phosphate removal in water treatment facilities.

1. Introduction

Nitrogen and phosphorus are essential nutrients which prompt the growth of photosynthetic algae and other photosynthetic aquatic life, leading to the acceleration of eutrophication and excessive loss of oxygen resources [1–3]. Red tides occasionally observed in lakes and seas are a typical example of the environmental problems caused by eutrophication. The rapid proliferation of toxic microalgae species and oxygen depletion via eutrophication have negative effects on various aquatic organisms and can reduce biological diversity [2–4]. The over-enrichment of these two nutrients usually results from human activities and can lead to the significant deterioration of water quality, which causes usage limitation. Therefore, protection and conservation of water resources are the most important tasks for both the health of human beings and the ecosystem.

Eutrophication can be avoided through control of either nitrogen or phosphorus. From ecological and economical points of view, the removal of phosphorus may be more effective than that of nitrogen because the concentration of phosphorus is generally lower in wastewater than is that of nitrogen. The usual forms of phosphorus that are found in aqueous solutions include the orthophosphate, polyphosphate, and organic phosphate. The orthophosphates are available for biological metabolism without further breakdown. The polyphosphates include those molecules with two or more phosphorus atom, oxygen atom, and, in some cases, hydrogen atom combined in a complex molecule. Polyphosphates undergo hydrolysis in aqueous solutions and revert to the orthophosphate forms. The organically bound phosphorus is usually of minor importance in most domestic wastes [5].

Conventional processes for phosphorus removal involve physical (settling and filtration), chemical (precipitation, ion exchange, and sorption), and biological processes (consumption by microorganisms or plants) [6–8]. The chemical process flocculation is a very attractive phosphorous-removal method because of its simple implementation. During the flocculation process, phosphate produces precipitates with metal salts such as calcium, magnesium, aluminum, or iron. A great variety of both natural and man-made materials plus industrial by-products have been applied as filter media for phosphorus removal from wastewater. In wetlands, especially, a majority of these materials have pH value > 7.0 and high Ca and/or CaO content. Thus, the main process of phosphorus retention used in constructed wetland is precipitation [9]. However, the flocculation and precipitation

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methods have some disadvantages, e.g., additional treatment of resultant sludge and the difficulty of phosphate recycling. To overcome these disadvantages, an ion exchange and adsorption method which is cost effective, easily performed, offers limited sludge production, and has the potential for retained phosphate recycling is needed to effectively remove phosphate. Concerning phosphate removal through an ion exchange and adsorption method, the use of a filter is more desirable than is an adsorbent.

Although there are many kinds of adsorbents for phosphate removal such as activated alumina treated with aluminum sulfate, boehmite, goethite, akaganeite, yttrium carbonate, and polymeric ligand exchanger [10–15], an additional collection process after the phosphate adsorption should be considered. The recycling requirements for these adsorbents should also be addressed.

Aluminum hydroxide ($Al(OH)_3$) is known for its use in a wide variety of applications such as antacid drugs [16], alumina catalyst precursors [17], and flame retardant materials [18]. Especially in the field of environmental science, aluminum hydroxide is popular for use as microorganism and phosphate absorbents in wastewater treatment [19,20]. Recently, the preparation of aluminum hydroxide through various methods has been reported, including the Bayer process [21], use of a rotating packed bed (RPB) [18], a sol–gel technique [22], pulse wire evaporation (PWE) with hydrolysis [23], and laser ablation [24]. However, none of these methods can produce aluminum hydroxide in the form of a film or layer, which could be applicable in various industrial sectors. In our previous reports [25–27], a process for fabricating an aluminum hydroxide film on aluminum substrate was proposed using a dilute alkali solution treatment and subsequent immersion in boiling water.

In the present study, an Al alloy foam filter covered with mesoporous $Al(OH)_3$ film was tested as a wastewater treatment filter. The mesoporous $Al(OH)_3$ film on which the ion exchange and adsorption of phosphate occur was generated using a simple alkali surface modification process. After the phosphate adsorption test on the Al alloy foam filter, we further describe a method for recycling used filters. Also, the structure, morphology, and ion adsorption properties of the Al alloy foam filter were investigated.

2. Experimental procedure

The substrate, an Al alloy foam plate (AA 6101, ERG Inc.), was purchased and cut into 10-mm diameter disks with constant thickness. Sodium hydroxide (NaOH, 93%, Duksan Pure Chemicals Co. Ltd.) was used as a reagent for the alkali surface modification. Pure water was obtained through double distillation followed by filtration with a Millipore Milli-Q Plus purification system. A simple alkali surface modification process was applied to the machined Al foam filter via a 5×10^{-3} M NaOH solution (pH 14) at 80 °C for one minute. After the alkali treatment, the Al foam filter was immediately immersed in boiling water for 30 min to stabilize the surface-modified layer.

The Al alloy foam filters were fixed in a filtering device, and the permeabilities were measured by determining the velocity of the flow using 100 ml of distilled water. For the evaluation of phosphate filtering capability, a 25-ml aqueous sample with a KH_2PO_4 (pH 6.2) concentration of 10 mg/l was filtered through up to 20 filters. After the phosphate filtering, a secondary alkali surface modification was performed on the used filter to confirm the possibility of filter recycling. The filters were re-treated by alkali solution by the same method and then filtering was performed once again. The measurement of phosphate was conducted using the ascorbic acid method in the APHA Standard Methods [28].

The microstructure and chemical state of the surface layer of the surface-modified Al foam filter were analyzed using scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), respectively. The size distribution of the pores and the specific surface area were measured using porosimetry and the Brunauer–Emmett–Teller (BET) method.

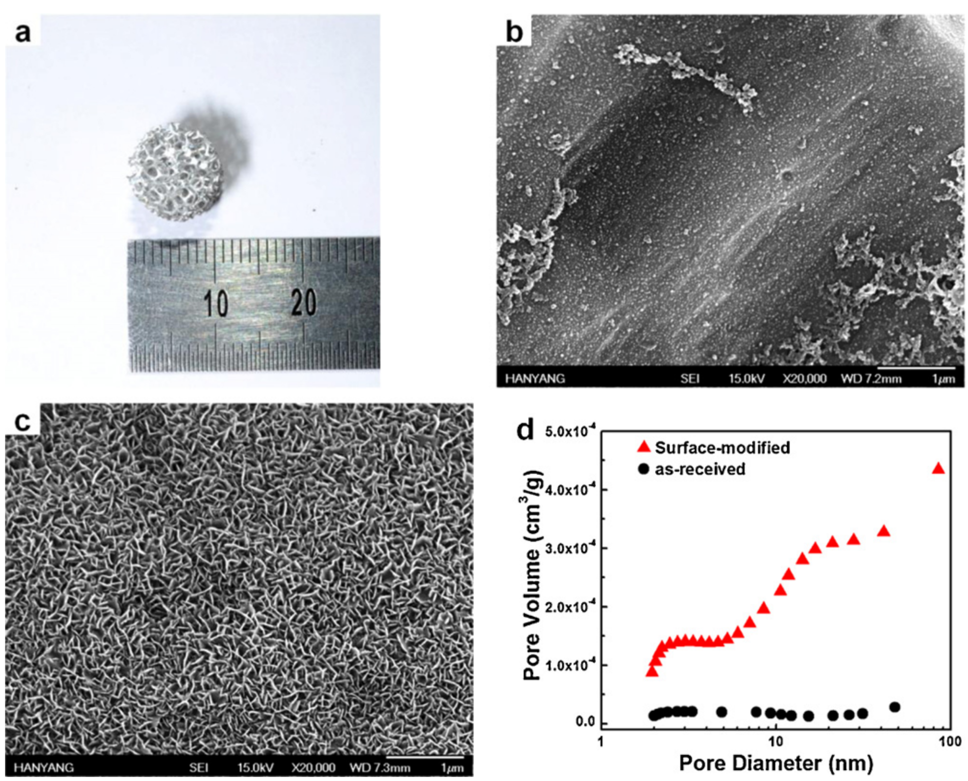

Fig. 1. (a) Photograph of a porous Al alloy foam filter, (b) SEM image of the as-received porous Al alloy foam filter surface, (c) SEM image of the surface-modified porous Al alloy foam filter, and (d) results of BET analysis on the porous Al alloy foam filter with and without surface modification.