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Autotrophic denitrification and chemical phosphate removal of agro-industrial wastewater by filtration with granular medium

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Abstract

A novel granular medium consisting (1.5–5 mm in diameter) of inert perlite particles as nuclei and an effective surface layer containing sulfur, $CaCO_3$ and $Mg(OH)_2$ was developed for advanced treatment of agro-industrial wastewater. The performance of the medium was examined with a laboratory-scale down-flow fixed-bed column reactor using piggery wastewater, which had been treated by an upflow anaerobic sludge blanket reactor and a trickling filter. The removal efficiency of NO_x^-–N was more than 70% with a NO_x^-–N loading rate of less than approximately 0.3 kg N m^{-3} d^{-1}; the removal efficiency dropped due to the accumulation of nitrite when the loading rate exceeded that value. A significant drop of phosphate and Mg^{2+} concentrations occurred when the effluent pH exceeded 7.9. Ammonium was removed with an average removal efficiency of 12.4%. These results indicated that the crystalline reaction of PO_4^{3-}, Mg^{2+} and NH_4^+ (MAP reaction) under alkaline conditions contributed to the removal of phosphate. This medium could be useful for the simultaneous reduction of nitrogenous and phosphorus compounds in biologically treated agro-industrial wastewater.

Keywords: Autotrophic denitrification; Sulfur oxidizing bacteria; Phosphate removal; MAP reaction; Swine wastewater

1. Introduction

The sulfur and limestone ($CaCO_3$) autotrophic denitrification (SLAD) process has increasingly been studied due to its high nitrate removal efficiency and cost-effectiveness (Flere and Zhang, 1999). Notwithstanding these advantages, the unbalanced consumption of sulfur and $CaCO_3$ remains a problem that needs to be worked out of this process before it is ready for industrial use. A granulated sulfur–$CaCO_3$ mixture material, named SC11, made from sulfur and $CaCO_3$ of equal quantities by weight, was developed by Kawaharazuka et al. (2001) to overcome this defect. This material was promising from the point of view of balancing the consumption of sulfur and $CaCO_3$, because $CaCO_3$ particles were homogeneously embedded in the sulfur matrix. However, efficient backwashing of the medium bed was difficult due to the large diameter (5–20 mm) of the granulated medium. Flere and Zhang (1999) have pointed out that sufficient backwashing was indispensable to the SLAD process.

The objective of this study was to develop a novel medium with both balanced consumption of constituents and an appropriate diameter for the backwashing process. The study also aimed at providing phosphorus removal activity to the medium.

2. Methods

2.1. Granular medium

The granular medium was prepared as follows. First, limestone powder (>98% $CaCO_3$ content; 300 mesh pass)

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and $Mg(OH)_2$ powder (10 μm diameter) were mixed with melted sulfur (120 °C) (weight ratio of $CaCO_3$, $Mg(OH)_2$ and S was 1:0.9:1). Perlite particles (1–3 mm diameter) were added to the melted mixture as nuclei and the melted mixture was coated on the particles with a granulating machine that maintained the temperature at 120 °C. The coated particles (1.5–5 mm diameter) were cooled and used for the experiment. The final composition of the medium by weight was 25.6% sulfur, 25.6% $CaCO_3$, 23% $Mg(OH)_2$, and 25.8% perlite. Mixing of the $CaCO_3$ was important to successful granulation of the medium. The density of the medium determined with the pycnometer method was 1.79.

2.2. Reactor and experimental procedure

Discharge water from the swine wastewater treatment plant at the Japanese National Institute of Livestock and Grassland Science was used as the influent for experiments. The plant consists of an anaerobic treatment reactor (UASB reactor) and an aerobic treatment reactor (trickling filter) for post-treatment. Fig. 1 shows a schematic representation of the experimental apparatus. The reactor was column-shaped (7.8 cm diameter and 65 cm height). A plastic punched-plate was attached at 2 cm above the reactor bottom to support the medium. The granular medium of 0.49 kg was put into the reactor (medium bed depth was 10 cm).

The influent was stored in a 60-L plastic tank maintained at about 10 °C. Newly collected influent (60-L) was supplied to the tank every two weeks. The influent water quality fluctuated throughout the experimental period due to the difference in the water quality of the collected discharge water and successive autochthonous change in the water quality due to biological and chemical reactions during storage. The influent was fed into the reactor by a diaphragm pump at a flow rate of 4 L d^{-1}, and the effluent was discharged from the bottom of the reactor. The hydraulic retention time (HRT) corresponding to the nominal bed volume (0.48 L) was 2.9 h. The initial water depth on the medium bed layer was 25 cm. Backwashing was carried out when the water depth exceeded 35 cm. The procedure for backwashing was as follows. Three seconds of aeration with a compressor was carried out 20 times with a 2-s pause between aerations, then water in the reactor was drained completely through two drain valves. The experiments were carried out at 20 °C in the dark.

2.3. Analytical methods

The pH was determined using a glass electrode. The concentrations of NO_2^-–N, NO_3^-–N, PO_4^{3-}–P and SO_4^{2-}–S were determined by ion chromatography using a Yokogawa IC–7000 Series II analyzer (Yokogawa Analytical Systems), attached to an Excelpak ICS–A23 column. The ammonium, Mg^{2+}, and Ca^{2+} concentrations were deter-

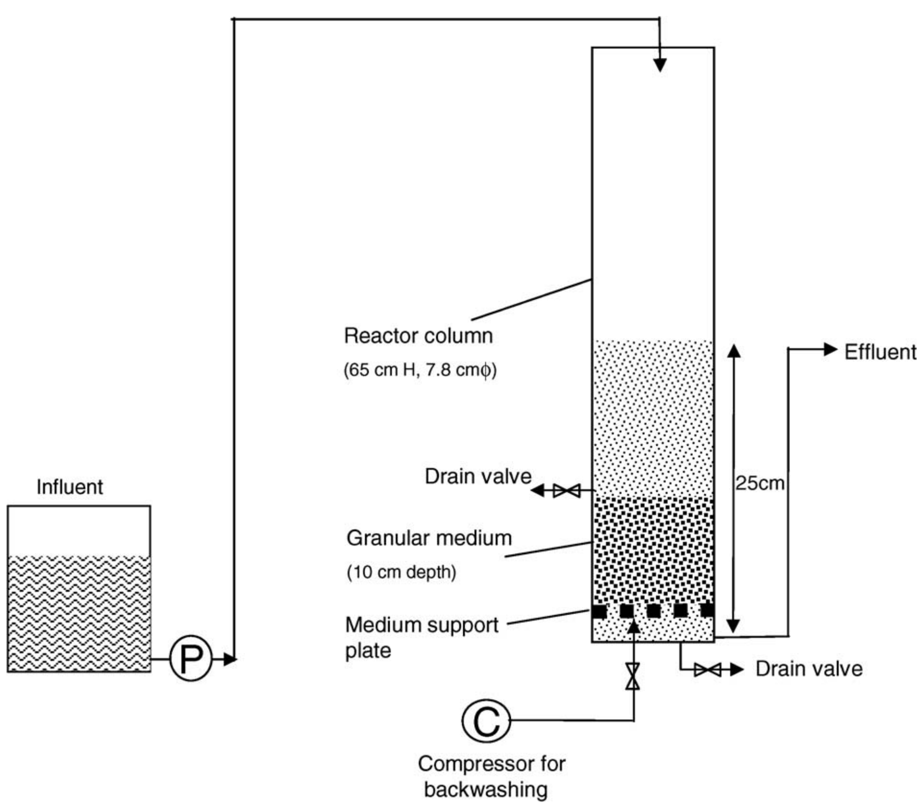

Fig. 1. Reactor for denitrification and phosphate removal using the granular medium.