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Effective start-up biofiltration method for Fe, Mn, and ammonia removal and bacterial community analysis

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HIGHLIGHTS

- An effective start-up method of biofilter was proposed.
- The start of Mn removal was affected by the procedure of inoculation.
- The *k* value of first order reaction for Mn removal was calculated.
- Manganese oxidizing bacteria (MnOB) showed richer diversity than nitrifier.
- MnOB also related to those of rarely reported in potable water treatment systems.

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ABSTRACT

Three identical lab-scale biofilters were employed to optimize the start-up process for simultaneous removal of iron (Fe), manganese (Mn), and ammonia from potable water supplies. Nitrifying sludge and backwashing sludge containing Mn-oxidizing bacteria (MnOB) were used as the inocula. The start-up strategies consisted of simultaneous and separate inoculation of the two kinds of sludge. The influent Fe was removed immediately when the biofilters began to operate. The effects of nitrification for ammonia removal showed no significant difference between these biofilters. However, the beginning of Mn removal with separate inoculation was faster than that of simultaneous inoculation. The Mn removal can be described by using first order reaction; and the *k* (rate constant, min^{-1}) values were 0.147 ± 0.007 (mean ± standard deviation) and 0.153 ± 0.006. Besides the commonly reported MnOB genus *Crenothrix*, MnOB genera were also found to be related to the genera rarely reported in the potable water treatment systems.

1. Introduction

Soluble divalent ions, iron (Fe) and manganese (Mn), often coexist together with ammonia in the groundwater. Such groundwater is usually unfit for drinking purposes without appropriate treatment. This is because the metal ions import an unpleasant metallic taste, produce metal oxides that can clog pipes and discolor clothes, and Mn can even cause neurotoxicity in humans (Gouzinis et al., 1998; Roth, 2006; Tekerlekopoulou and Vayenas, 2007). Additionally, in water supply plants, ammonia in raw water needs to be removed before the water is disinfected with chlorine, as it consumes chlorine significantly and produces chloramines in the disinfection process (Tekerlekopoulou et al., 2013). Therefore, for some water supply plants, removal of Fe, Mn and ammonia from groundwater is a daily requirement.

The three contaminants can be successfully removed by using physicochemical or biological methods, but there are still some advantages and disadvantages in these methods.

Among the physicochemical methods, chlorination, ion exchange, and membrane filtration are the most effective removal methods of these contaminants (Oehmen et al., 2006; Vaaramaa and Lehto, 2003; Van Benschoten et al., 1992; Wong, 1984). The quality of the water produced from this water treatment process is ensured. However, the presence of ammonia requires the use of high amounts of chlorine, as up to 10 mg of chlorine is required to remove 1.0 mg of ammonia (Reeves, 1972). Additionally, the oxidant should be continuously added as the operation of the plants, and consequently, the chemical oxidation process is usually limited due to the high volumes of sludge and the cost of the oxidants (Tekerlekopoulou et al., 2013). The application of ion

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exchange and membrane filtration are limited due to their higher capital and operational costs (Mouchet, 1992).

As an alternative, biological treatment processes have drawn much attention in recent years, since they do not require extra chemical oxidants. More importantly, simultaneous removal of these contaminants could be achieved by using a one-stage biofilter (Abu Hasan et al., 2012; Gouzinis et al., 1998; Štembal et al., 2004; Tekerlekopoulou and Vayenas, 2008), which simplifies the treatment processes and reduces costs. Li et al. (2005) demonstrated that using biological processes in a water supply plant (total treatment capacity: 12×10^4 m^3 day^{-1}) could reduce investment costs by 50 million yuan (¥), and operational and maintenance costs by ¥12,000 per day. Meanwhile, Tekerlekopoulou et al. (2013) describing and summarizing the work of Mouchet (1992) noted that a shift from abiotic to biotic methods could substantially increase treatment capacity and reduce operational costs by up to 80%. Biological treatment technology has been applied in practical engineering contexts in many countries (Burger et al., 2008; Katsoyiannis and Zouboulis, 2004; Li, 2004; Pacini et al., 2005; Štembal et al., 2004), e.g. Canada, Germany, China, Croatia, and the USA. However, it is also should be noted that the unavoidable start-up period of the biofilters can be the main drawback for its application because it is difficult for the quality of produced water to meet required standards during the start-up period.

Backwashing sludge or matured biofilter supporting materials are usually collected as inocula to shorten the start-up time of the biofilters. Moreover, the removal of Fe or ammonia is much easier than Mn removal due to the different water redox potentials they need. This makes Mn removal a decisive factor affecting the start-up period (Mouchet, 1992). The inoculation levels of microorganisms in a newly built full-scale biofilter seem to be insufficient to achieve simultaneous removal immediately. Although reports describing the profile of Mn concentrations during the start-up period of full-scale biofilters are rare, Li et al. (2005) demonstrated that a start-up period of 2–3 months was necessary. The required values of standards for Fe, Mn, and ammonia in China are 0.3 mg/L, 0.1 mg/L, and 0.5 mg/L, respectively (SEPA, 2002).Therefore, ways to shorten the start-up period is of great importance for the further application of this biotechnology.

On the other hand, nitrifying bacteria as the functional microorganisms for ammonia removal have been well studied; and *Gallionella* was also found to have the ability to oxidize Fe only. However, there are still some difficulties in studying Mn-oxidizing microorganisms because the Mn-oxidizing groups, which are characterized by the ability to catalyze the oxidation of soluble Mn to insoluble Mn oxides, include many different organisms, e.g. a variety of bacteria, fungi, algae, and even eukaryotes (Ghiorse, 1984). The bacteria groups are often found naturally in different habitats, e.g., deep-sea manganese nodules, lake waters, groundwater, bay sediments, and soils (Cahyani et al., 2007). *Leptothrix*, *Sphaerotilus*, *Clonothrix*, and *Crenothrix* have been reported as common Fe/Mn-oxidizing genera in potable water treatment systems. While some other bacteria associated with Mn deposits or mining were also found to have the capacity to oxidize Mn, e.g. *Sphingomonas*, *Flavobacterium*, *Janthinobacterium*, and *Acinetobacter* (Carmichael et al., 2013; Miller et al., 2012), it is interesting that they are rarely reported in potable water-treatment systems. Considering the influent Mn was oxidized and fixed on the surface of filtration materials, the Mn deposits would accumulate in the biofilter bed. Therefore, the biofilter will provide space for these Mn-oxidizing bacteria (MnOB) to grow, and it is seems sensible to study the diversity of MnOB in the potable water treatment biofilters further.

This paper focuses on how to shorten the start-up period of the biofilter for the removal of Fe, Mn, and ammonia simultaneously, by starting up the lab-scale biofilters with different methods of inoculation. Mn removal performance was also evaluated as a decisive factor affecting the start-up period. Meanwhile, molecular biotechnology (i.e. cloning and sequencing) was applied to further study the microbial community structure and diversity in the biofilters.

2. Methods

2.1. Device and synthetic water

Three identical lab-scale gravity biofilters (named R1, R2, and R3) made of Plexiglass, as shown in Fig. 1, were adopted for the simultaneous removal process. Each biofilter consisted of a 50-cm-high Plexiglas column with an inside diameter of 10 cm; other reactor components consisted of an influent tank, a backwashing tank, a flowmeter installed in the outflow pipeline, a water distributor above the filter and two peristaltic pumps for influent and backwashing purposes.

There was a 10-cm-high supporting layer of cobblestone at bottom of the biofilter with a cobblestone particle size of 0.5–1 cm.

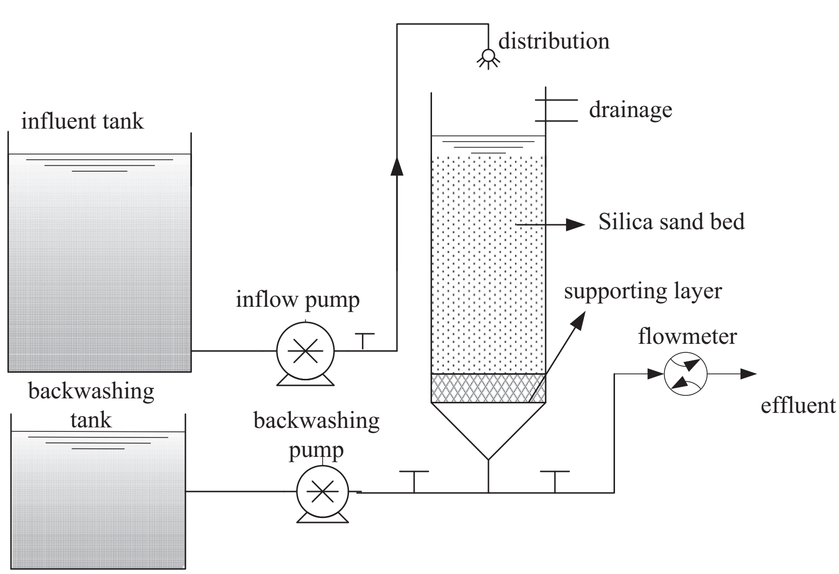

Fig. 1. Schematic of the biofilter reactor in this study.