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Improving biodegradation potential of domestic wastewater by manipulating the size distribution of organic matter

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ABSTRACT

Carbon source is a critical constraint on nutrient removal in domestic wastewater treatment. However, the functions of particulate organic matter (POM) and some organics with high molecular weight (HMW) are overlooked in the conventional process, as they cannot be directly assimilated into cells during microbial metabolism. This further aggravates the problem of carbon source shortage and thus affects the effluent quality. Therefore, to better characterize organic matter (OM) based MW distribution, microfiltration/ultrafiltration/nanofiltration (MF/UF/NF) membranes were used in parallel to fractionate OM, which obtained seven fractions. Hydrolysis acidification (HA) was adopted to manipulate the MW distribution of dissolved organic matter (DOM) and further explore the correlation between molecular size and biodegradability. Results showed that HA pretreatment of wastewater not only promoted transformation from POM to DOM, but also boosted biodegradability. After 8 hr of HA, the concentration of dissolved organic carbon (DOC) increased by 65%, from the initial value of 20.25 to 33.48 mg/L, and the biodegradability index (BOD5 (biochemical oxygen demand)/SCOD (soluble chemical oxygen demand)) increased from 0.52 to 0.74. Using MW distribution analysis and composition optimization, a new understanding on the characteristics of organics in wastewater was obtained, which is of importance to solving low C/N wastewater treatment in engineering practice.

Introduction

Environmental sustainability and freshwater ecosystem health have gained widespread attention in recent years (Wang et al., 2008; Liu et al., 2013). Nutrient input from intensified human-induced activities, especially nitrogen (N) and phosphorus (P) from point and diffuse sources, is a major force causing aquatic phytoplankton blooms such as that of toxic cyanobacteria (Sebastia et al., 2012), which result in severe degradation of freshwater ecosystems (Burford et al., 2012; Dailer et al., 2012) and threaten drinking water supplies (Dudgeon et al., 2006).

Due to serious point-source contamination, many wastewater treatment processes have been developed to reduce excessive N and P delivery into water bodies in an attempt to mitigate the effects of eutrophication (White and Irvine, 2003; Xu et al., 2011). In most processes, however, the lack of a conventional, soluble and readily biodegradable carbon source in raw wastewater has restricted nutrient removal efficiency (Lee et al., 2010; Liu et al., 2013). Nowadays, the addition of an external easily biodegradable carbon source (*e.g.*, methanol and sodium acetate) is widely used to fulfill effluent demands for nutrient removal with biological process. Besides, an alternative usage of activated sludge with hydrolysis-acidification treatment can

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produce a mass of internal carbon source for existing biological processes. Nevertheless, these methods are generally considered as an unsustainable approach due to the increase of operational cost and management complexity.

Establishing organic matter (OM) characteristics and exploring appropriate ways to optimize carbon source quality have become important areas of research. The OM in domestic wastewater can usually be divided into particulate and dissolved fractions (Raunkjer et al., 1994; Singh et al., 2005). Previous studies (Fenu et al., 2010) have indicated that although particulate organic matter (POM) is a potential denitrification carbon source, much less is known about its use in conventional biological nutrient removal (BNR) because of its relatively low denitrification rate (Zheng et al., 2013). Currently, the vast majority of POM in wastewater is removed by the primary settling tank in conventional wastewater treatment plants (WWTPs). In most of domestic wastewater, POM is the main component of carbon source and the dissolved fraction account for 20%–30% of total organic compounds (Zheng et al., 2013), which explains why there is insufficient carbon for denitrification. It is essential, therefore, to establish an in-depth technique to utilize these neglected organics, which will contribute to the reduction of wastewater treatment costs.

Wastewater OM has been traditionally characterized by chemical oxygen demand (COD), total organic carbon (TOC) and biochemical oxygen demand (BOD). However, these chemical indexes only provide a macroscopic view, without defining carbon source component distribution characteristics. Therefore, some researchers (Ged and Boyer, 2013) started to focus on understanding the composition of OM with a wide range of molecular weights. A broad spectrum of membrane ranging from microfiltration (MF) to ultrafiltration (UF) to nanofiltration (NF) with molecular weight cut-off (MWCO) is a useful approach for rapid determination of organic matter (OM) reactivity and treatability based on molecular size (Bridgeman et al., 2011; Ishii and Boyer, 2012; Wei et al., 2014). Combining different sizes of membranes can well separate the OM with different molecular sizes in wastewaters.

The structure and composition of DOM can be difficult to determine due to its varied size, ranging from several hundred to tens of thousands of Dalton (Da) (Romera-Castillo et al., 2014). It contains low molecular weight (LMW) fractions, which are typically smaller, more labile compounds such as aliphatics, free amino acids and sugars, as well as various high molecular weight (HMW) compounds such as proteins, enzymes, humic acid and other mixtures (Kirchman, 2003; Saadi et al., 2006). Some easily biodegradable DOM (*e.g.*, LMW substrates) often with simple structure and highly biological oxidation can enter the cell cycle directly (Escobar and Randall, 2001; Santos et al., 2013), but most HMW DOM must first undergo hydrolysis and then oxidization to form acetyl-CoA before it can enter the cell cycle (Li and Yang, 2007).

Hydrolysis acidification (HA) is a potential biochemical pretreatment step that can enhance wastewater biodegradability by decomposing complicated molecules into smaller ones and suspended solids (SS) into dissolvable matter by hydrolysis and acidification bacteria (Bravo et al., 2009; Ma et al., 2009). HA not only changes the MW distribution of DOM, but also avoids the loss of high quality carbon in the methanogenic process (Genschow et al., 1996; Wang et al., 2014).

The distribution of MW may be a useful indicator of carbon source quality as well as a potential predictor of bioavailability (Hill et al., 2009). In recent years, attention has shifted from the total concentration to the different MW level of OM to better understand organic distribution behavior and transformation mechanisms (Hertkorn et al., 2006; Panagiotopoulos et al., 2013). Therefore, fractionating wastewater OM into different MW fractions could help expand knowledge on wastewater biodegradability characteristics and assist in the design of appropriate treatment processes (Dulekgurgen et al., 2006; Leiviska et al., 2008; Huang et al., 2010). However, little has been reported on the MW distribution and transformation of DOM during HA process.

In this study, a pilot-scale HA membrane bioreactor was established and operated to gain further insights into OM features in combination with MW distribution. The objectives are to advance our knowledge on (1) the availability of POM and transformation characteristics between POM and DOM, (2) the MW distribution of DOM and their dynamic changes with HA duration, and (3) the relationship between biodegradability and MW fractions.

1. Materials and methods

1.1. HA reactor

A schematic diagram of the bench-scale HA reactor is shown in Fig. 1. It consisted of a 1 m high cylinder with a 50 cm diameter. Domestic wastewater was pumped into the reactor with a small amount of oxygen to avoid the formation of an anaerobic state in the HA system. The reactor was filled with a biofilm carrier, on which microorganisms from activated sludge were cultured or acclimated. Water samples were collected at different hydraulic retention time (HRT), which were determined by experimental requirements (0, 4, 8, 12, 16, 20 and 24 hr). The operating temperature of the HA system was adjusted according to the ambient temperature and inflow wastewater temperature.

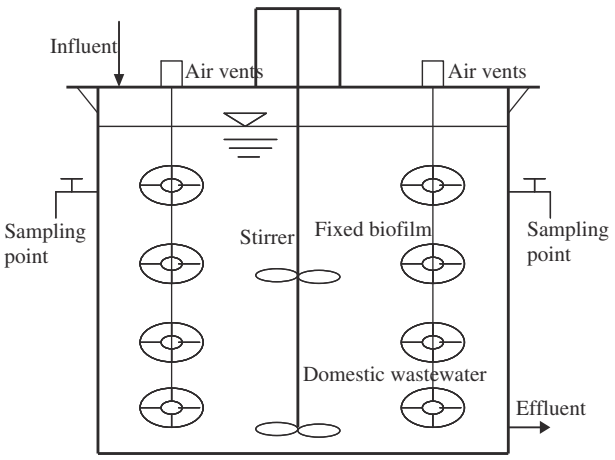

Fig. 1 – Schematic diagram of the hydrolysis acidification (HA) reactor with fixed biofilms.