



Research article

Biological nitrate removal using a food waste-derived carbon source in synthetic wastewater and real sewage



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ABSTRACT

The production of volatile fatty acids (VFAs) from food waste to improve biological nutrient removal has drawn much attention. In this study, acidogenic liquid from food waste was used as an alternative carbon source for synthetic wastewater treatment. C/N ratios of 5 and 6 were suitable for denitrification, and the change in acidogenic liquid composition had no negative effect on denitrification. The denitrification rates using optimal carbon-to-nitrate ratios of acidogenic liquid were more than 25 mg NO₃-N/(gVSS·h). At the same time, acidogenic liquid was used to improve nutrient removal from summer and winter sewage. C/N ratios of 5 and 6 were acceptable for summer sewage treatment. Total nitrogen in the final effluent was less than 7 mg/L. Two additional hours were required for winter sewage treatment, and the C/N ratio had to be >6.

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1. Introduction

The removal of nitrogen from wastewater is important to ensure environmental protection of surface waters. High concentrations of nitrogen compounds discharged into the environment can cause serious problems, such as deterioration of water sources and eutrophication of rivers and lakes (Anderson et al., 2002; Zhang et al., 1996). Biological nutrient removal (BNR) processes are commonly used to remove nitrogen from wastewater, namely, biological denitrification can transform nitrate and nitrite in the presence of several heterotrophic bacteria. For efficient denitrification, the wastewater must contain sufficient carbon source to ensure bacterial metabolism. Generally, methanol, ethanol and acetate were used to complement the carbon source in wastewater treatment plant. However, the denitrification rate of methanol was comparative lower because of its toxicity (Swinarski et al., 2009; Wei et al., 2012), while the cost of ethanol and acetate was much more expensive (Strong et al., 2011; Biradar et al., 2010).

Thus, numerous studies have explored cheap and effective alternative carbon sources. Solid carbon sources, such as paper,

wood, and straw were proposed (Volkita et al., 1996; Yamashita et al., 2011; Ines et al., 1998; Boussaid et al., 1988) as alternative carbon source, yet the denitrification rates were disappointed. Alternatively, volatile fatty acids (VFAs), which could easily be used because of their small molecular weight and direct role in bacterial metabolism, were considered suitable carbon source for BNR (Elefsiniotis and Li, 2006; Xu, 1996). Several studies have reported using VFA-rich liquids produced by anaerobic digestion as carbon sources for denitrification (Zeng et al., 2012; Elefsiniotis et al., 2004). In Soares et al. (2010) study, fermented primary sludge and disintegrated surplus-activated sludge were used as carbon source and the denitrification rates were only 1.4 and 1.9 mg NO₃-N/(gVSS·h), respectively. In other studies, the denitrification rates could reach up to 23.7 and 14.9 mg NO₃-N/(gVSS·h) using fermented primary sludge (Kampas et al., 2009) and disintegrated activated sludge (Aesoy and Odegaard, 1994), respectively.

Compared with activated sludge, food waste contained more easily degradable organic matters was more suitable for this technology. Lim et al. (2008) and Jiang et al. (2013) reported that VFA-rich liquids derived from food waste (acidogenic liquid) could be used as denitrification carbon sources. However, the denitrification rate of acidogenic liquid was only 3.6 mg NO₃-N/(gVSS·h) in Lim's study. Also, few studies were focused on the key factors of denitrification using acidogenic liquid, such as the running

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temperature, the dosage and ingredient of acidogenic liquid.

To improve the technology of using food waste-derived carbon source, we studied variations in nitrogen concentrations of synthetic wastewater using high- and low-C/N ratio acidogenic liquids as alternative carbon sources at different COD (chemical oxygen demand)-to-nitrogen ratios and compared them with industrial alternative carbon. Furthermore, acidogenic liquid from food waste was used as an alternative carbon source to treat summer and winter sewage, and compared the effect of temperature and different seasons on sewage. This study investigated whether acidogenic liquid from food waste is useful for the denitrification of wastewater.

2. Materials and methods

2.1. Fermentation and acidogenesis of food waste

The acidogenic liquid was generated using simulated food waste composed of 35% rice, 45% cabbage, 16% pork, and 4% tofu by weight. The fermentation conditions were controlled for pH (6.0), temperature (35 °C and 45 °C), and HRT (5 days) (Jiang et al., 2013). With differences in temperature, we obtained two types of acidogenic liquid, designated a and b, which have high 88 and low 65 carbon-to-nitrogen ratios, respectively. The acidogenic liquid separated from the solids by centrifugation and filtration with filter paper. The composition of these two acidogenic liquids is shown in Table 1.

2.2. Sequencing batch reactor

The sequencing batch reactor (SBR), which is used in predictive tests and real wastewater tests, consisted of a reactor, pumps, ion-selective electrodes (pH), and tanks. The reactor was made of plastic cylinders with a 9-L working volume. We could adjust the gas flow for each cycle according to the time sequence to insure the oxygen concentration over 3.5 mg/L during the aerobic phases. During the operation of the SBR, the volumes of sludge and treated water were maintained at both 4.5 L, respectively and only blow 20 ml of alternative carbon source was added according to the carbon-to-nitrogen ratios. The reactor was operated at 25 °C, excluding winter when the water temperature was 15 °C. The SBR had an around 25-day solid retention time (SRT) by discharging a part of sludge keeping the concentration of activated sludge at 2000 to 2300 mgVSS/L. The operational cycle for the SBR included 10 min of filling, 4 h of anoxic period with mixing, and 30 min of settling, followed by 10 min decanting for predictive tests, and then 10 min of filling, 16 h of aeration with mixing, 4 or 6 h of anoxic period with mixing, 30 min of settling, and finally, 20 min of decanting for summer and winter sewage tests, respectively.

2.3. Experimental materials and processes

The synthetic wastewater used for predictive tests contained 30 mg/L of NO₃-N, 3 mg/L of PO₄-P, 4 mg/L of CaCl₂-Ca, 18 mg/L of

Mg, 0.9 mg/L of Fe, 0.02 mg/L of Cu, and 0.1 mg/L of Mn (Cen Zhao et al., 2014). Real wastewater included summer and winter sewage from the Xiaojiahe wastewater treatment plant. The summer sewage had low NH₄⁺ concentrations at 24–26 mg/L; NO₃⁻ and COD concentrations were less than 1 mg/L and 180.5–230.5 mg/L, respectively. The winter sewage had high NH₄⁺ concentrations of 35–40 mg/L; NO₃⁻ and COD concentrations were less than 0.1 mg/L and 187.2–216.2 mg/L, respectively.

Fermentation broths were produced by anaerobic fermentation of food wastes, as described previously. The carbon source was separately added to the SBR system. In predictive tests, the carbon source was added at the beginning of the anoxic period under anoxic conditions. There was no other carbon source except the alternative carbon source in the BNR system. In real waste tests, the carbon source was added after aeration.

Samples were taken every 1 h, with multiple samples taken during the first hour. These samples were analyzed after centrifugation and filtration with filter paper.

2.4. Analytical methods

COD, VFAs, ethanol, nitrate, nitrite, and ammonia nitrogen were measured after centrifugation (15,000 rpm for 15 min) and filtration (0.45 μm). VFAs (acetate, propionate, butyrate, isobutyrate, valerate, and isovalerate) and ethanol were measured using a gas chromatograph (Shimadzu, GC-2010 plus) equipped with a capillary column (stabliwax-DA, 30 m × 0.32 mm × 0.25 μm) and a flame ionization detector (FID). The temperature of the injector and detector were 220 and 250 °C, respectively. The column temperature was increased from 60 to 150 °C at a rate of 7 °C/min, maintained at 150 °C for 5 min, increased to 230 °C at a rate of 20 °C/min, and maintained at 230 °C for an additional 10 min. The concentration of nitrate was determined using ultraviolet spectrophotometry, that of nitrite was determined based on N-(1-naphthyl)-ethylenediamine dihydrochloride spectrophotometry, and the concentration of ammonia nitrogen was determined using Nessler reagent spectrophotometry. COD was measured using the titration method after digestion with a digestion instrument (APHA-WPCF, 1998).

3. Results and discussion

3.1. Nitrate removal results for different types of acidogenic liquid

A comparison of the two types of acidogenic liquid showed that the denitrification process and variation in nutrients were similar. Nitrate and nitrite could almost be removed at suitable dosages. However, the ammonia concentration was always low (under 5 mg/L) (Fig. 1).

Using acidogenic liquid a as a carbon source, when COD/N was 3, the nitrate concentration decreased rapidly from 29.6 to 10.6 mg/L during the first hour. The denitrification rate then slowed during the last 3 h and reached a nitrate concentration of 2.8 mg/L. At an increased dose of acidogenic liquid with COD/N of 4, 5, or 6, the

Table 1
Different acidogenic liquid compositions.

No.		Ethanol	Acetate	Propionate	Isobutyrate	Butyrate	Butylcarboxylic acid
a acidogenic liquid ^a	Concentration (g/L)	3.6	11.38	16.17	0.07	6.69	0.27
	VFA ratio (%)	–	32.91	46.76	0.20	19.35	0.77
b acidogenic liquid ^b	Concentration (g/L)	1.3	15.9	15.8	0.48	10.12	2.70
	VFA ratio (%)	–	35.33	35.11	1.07	22.49	5.5

^a a acidogenic liquid from food waste: high carbon-to-nitrogen ratio.

^b b acidogenic liquid from food waste: low carbon-to-nitrogen ratio.

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