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Algal uptake of dissolved organic nitrogen in wastewater treatment plants

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A B S T R A C T

The algal uptake of dissolved organic nitrogen (DON) in the anaerobic–anoxic–oxic (A_2O) process was investigated in this study. Anaerobic, aerobic and effluent DON samples from two wastewater treatment plants (WWTPs) were separated into hydrophilic and hydrophobic fractions using a DAX-8 resin coupled with an anion exchange resin and a nanofiltration (NF) pretreatment. Hydrophilic DON accounted for 66.66%–88.74% of the entire DON for the two plants evaluated. After a 15-day incubation, 16.95%–91.75% DON was bioavailable for algal growth, and untreated samples exhibited higher DON bioavailability, with 52.83% DON average uptake rates, compared with the hydrophilic and hydrophobic fractions (45.53% and 44.40%, respectively) because the pretreatment caused the inorganic salt to be resistant to algae. Anaerobic untreated samples, hydrophilic fractions and hydrophobic fractions showed higher DON reduction rates and higher biomass accumulation compared with the other DON fractions due to the decomposition of resistant organics by anaerobic and anoxic bacteria. DON in aerobic and effluent samples of plant A was more bioavailable than that of plant B with usages of 27.49%–55.26% DON. DON bioavailability in the anaerobic–anoxic–oxic process decreased in the following order: anaerobic > effluent > aerobic. The DON contents were reduced after anaerobic treatment in the two plants. The EEM-PARAFAC model identified three DON components, including two humic acid-like substances and one protein-like substance in plant A and two protein-like substances and one humic acid-like substance in plant B. DON fractions were utilized for algal growth and were produced due to the release of soluble microbial products during algal metabolism and lysis.

Introduction

In recent years, enhanced nutrient removal technologies have been applied in municipal and wastewater treatment plants to meet gradually stricter emission standards (Simsek et al., 2013; Qin et al., 2015). The majority of the dissolved inorganic nitrogen (DIN) in wastewater is removed after biological treatment; thus, dissolved organic nitrogen (DON) became the primary nitrogen species in the total dissolved nitrogen (TDN) content in effluents. Liu et al. (2012) reported that DON was the predominant nitrogen species in the effluent of eight municipal wastewater treatment plants. In addition, effluent DON was bioavailable to algae and plankton (Sattayatewa et al., 2009; Urgun-Demirtas et al., 2008), which could increase the nutrient level in natural water. Some

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DON fractions were directly taken up by algae; other forms that could be degraded into low-molecular-weight (MW) DON were also bioavailable (Pehlivanoglu-Mantas and Sedlak, 2004; Liu et al., 2012). Some DON fractions can be mineralized to ammonia or nitrate and used by bacteria and algae (Bronk et al., 2007).

Algae can effectively accumulate heavy metals from the environment (Chakraborty and Owens, 2014; Mani and Kumar, 2014) and can uptake DON in wastewater effluent (Liu et al., 2012; Pehlivanoglu-Mantas and Sedlak, 2004; Qin et al., 2015). Liu et al. (2012) separated the effluent DON of a biological nutrient removal process into hydrophilic and hydrophobic DON fractions and studied their bioavailability. During a 14-day incubation period, hydrophilic DON accounted for 80% DON-stimulated algal growth, whereas hydrophobic DON had only a slight effect on algal growth. Sattayatewa et al. (2009) developed a method to determine the amount of biodegradable DON (BDON) in the effluent from a 4-stage Bardenpho process. They used a pure culture alga *Selenastrum capricornutum* as inocula for BDON measurements and reported that approximately 28%–57% of the effluent DON was bioavailable or biodegradable for algae in the presence and absence of bacteria. However, few studies have examined the algal uptake of DON along the treatment trains. Simsek et al. (2013) examined the fate of BDON through a full-scale two-stage trickling filter process of a wastewater treatment facility. BDON was primarily removed by trickling filters (in both stages), and the average BDON removal efficiency was 72% with a final effluent BDON concentration of 1.80 mg N/L. DON biodegradability (BDON/DON) for raw wastewater and for samples from all treatment units varied from 51% to 69%. The anaerobic–anoxic–oxic (A_2O) process has been widely applied in municipal sewage treatment plants in China. Few studies have been performed on the algal uptake of DON in this process. Understanding algal uptake of DON in the A_2O process is valuable for estimating the eutrophication contribution of DON fractions in wastewater.

The objective of this study was to determine the algal uptake of hydrophilic and hydrophobic DON fractions during the A_2O processes. Moreover, fluorescence excitation–emission matrices (EEMs) combined with parallel factor analysis (PARAFAC) were applied to characterize the DON composition during the A_2O processes and to monitor the changes in the DON fractions during the bioassay.

1. Materials and methods

1.1. Sample collection

Wastewater samples were collected from two wastewater treatment plants (WWTPs) equipped with A_2O processes in Changzhou City. The process of plant A consists of a primary clarifier followed by anaerobic, anoxic and anaerobic procedures with an average flux of 150,000 m^3/day municipal wastewater. Plant B receives industrial (40%) and domestic wastewater (60%) from Changzhou City with an average flux of 100,000 m^3/day, and the process includes a primary clarifier as well as hydrolytic acidification, anaerobic, anoxic and aerobic procedures. The effluent of the two plants is discharged into Lake Taihu. The samples were collected from anaerobic, aerobic and effluent units along the treatment train for both plants. All samples were collected in polyethylene containers and were immediately transported to the laboratory. The grab samples were filtered through 0.45 and 0.22 μm cellulose acetate membranes and then stored at 4°C prior to use. The basic characteristics of the wastewater samples are shown in Table 1.

1.2. Resin separation

A DAX-8 resin was employed to separate the DON of anaerobic, aerobic and effluent samples into hydrophilic and hydrophobic DON fractions (Liu et al., 2012). Two liters of all the wastewater samples were first acidified to pH 2.0 with HCl and then pumped through the DAX-8 resin with a flow rate of 1.5 mL/min. The effluent liquids were collected and passed through an anion exchange resin (Dowex® 1 × 8 chloride form, 100–200 mesh, Sigma) to eliminate the NO_3^-. The final effluent liquids were collected as the hydrophilic DON fraction. The DAX-8 resin was then eluted in the reverse direction with 800 mL of 0.1 mol/L NaOH at a flow rate of 1.5 mL/min to yield the hydrophobic DON fraction. In addition, the raw wastewater samples were passed directly through the anion exchange resin to reduce the amount of nitrate nitrogen, and the effluent was considered as the untreated sample.

1.3. NF pretreatment

The nanofiltration (NF) system was applied to improve the measurement accuracy and to reduce the ammonia nitrogen. The NF system was pressurized using a high-purity nitrogen gas cylinder, and 0.52 MPa (75 psi) was the maximum pressure according to the manufacturer's instructions. The stirrer speed was controlled at 100 to 120 rpm by a magnetic stirrer to minimize the effect of concentration polarization. After the DAX-8 resin and anion exchange resin treatment was complete, the DON contents in the untreated samples, the hydrophilic fraction of the aerobic and effluent procedures and all of the hydrophobic fractions were less than 0 due to the high DIN/TDN ratios in the samples. Therefore, NF pretreatment was required to reduce the ammonia nitrogen in these DON fractions. One liter each of the aerobic and effluent untreated samples and the hydrophilic fraction and 800 mL of the hydrophobic fraction were pretreated using the NF system; 500 and 400 mL were collected, respectively. Additional details about the NF pretreatment procedures were given by Huo et al. (2014). The retentate was stored at 4°C for further analysis and for biological culture.

Table 1 – Basic characteristics of wastewater samples in anaerobic, aerobic and effluent samples of plants A and B.

	Sample	TN (mg/L)	NH_3–N (mg/L)	TP (mg/L)
Plant A	Anaerobic sample	14.4	14	2.30
	Aerobic sample	14.11	1.73	1.36
	Effluent	13.53	0.38	0.44
Plant B	Anaerobic sample	17.41	17.27	1.01
	Aerobic sample	13.78	2.94	2.65
	Effluent	12.15	1.46	0.76