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Effect of seed sludge on nitrogen removal in a novel upflow microaerobic sludge reactor for treating piggery wastewater

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HIGHLIGHTS

- Two upflow microaerobic sludge reactors were constructed to treat MFPW.
- Aerobic and anaerobic activated sludge (S) were the inocula, respectively.
- Aerobic S was easier being accumulated than anaerobic S, only feasible for low NLR.
- The accumulated anaerobic AS was feasible for treating MFPW with higher NLR.
- An increased loading rate changed microbial community structure and removal load.

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ABSTRACT

Anaerobic activated sludge (AnaS) and aerobic activated sludge (AerS) were used to start up a novel upflow microaerobic sludge reactor (UMSR), respectively, and the nitrogen removal in the two reactors were evaluated when treating low C/N ratio manure-free piggery wastewater with a COD/TN ration of about 0.85. With the same hydraulic retention time 8 h and TN loading rate (NLR) 0.42 kg/(m^3 d), the UMSR (R2) inoculated with AerS could reach its steady state earlier and obtained a better TN removal than that in the UMSR (R1) inoculated with AnaS. However, the accumulated AnaS made R1 show a better capability in bearing shock load and demonstrated an excellent NH_4^+-N and TN removal with a NLR as high as 1.07 kg/(m^3 d). Microbial community structure of the accumulated AerS and AnaS were observable different. The decreased proportion of nitrifiers restricted the ammonium oxidation in R2, and resulting in a decrease in TN removal.

1. Introduction

With the large-scale and intensive development of pig industry, more and more piggery wastewater is discharged from the pig farms (Liwei et al., 2011). The wastewater is rich in nutrients and can cause severe harm to the natural environment and human health (Daverey et al., 2013; Zhao et al., 2014). There are three main approaches to remove manure from piggery in China, namely urine-free manure (UFM), combined manure with urine (CMU) and soaked manure with urine (SMU) (Li et al., 2016). As a traditional mode, UFM collection is still widely used in China (Zhao et al., 2014). The collected pig manure can be recycled as fertilizer (Zoccarato et al., 1995), but resulting in an increased ammonium (NH_4^+-N) and a decreased chemical oxygen demand (COD) in the manure-free piggery wastewater (MFPW) (Zhao et al., 2014). The nitrogen removal is a serious challenge in treating MFPW due to the high NH_4^+-N and the low C/N ratio (Kishida et al., 2003). Although traditional anaerobic–aerobic combined process is an engineered treatment technology with robust adaptability (Zheng et al., 2012), the cost of which is still high when treating low C/N ratio wastewater because some extra physical chemistry pretreatment has to be used for a feasible C/N ratio to the subsequent traditional biological nitrogen removal process (Bernet et al., 2000).

Autotrophic denitrification such as anaerobic ammonium oxidation (anammox) is considered a cost-effective alternative to traditional denitrification process in treating low C/N ratio wastewater because of no need of extra carbon source (Windey et al., 2005). In the process, ammonium, S(0) and Fe(0) instead of organic carbon provide electron for reducing nitrite to N_2 and/or N_2O (Batchelor and Lawrence, 1978; Strous et al., 1999; Till et al., 1998). Moreover, the autotrophic nitrogen removal process has a lower sludge production compared with heterotrophic process (Van Loosdrecht and Jetten, 1998). Therefore, autotrophic

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denitrification is considered an essential process for nitrogen removal in treating MFPW with low C/N ratio (Sliekers et al., 2002). However, the total nitrogen (TN) in the wastewater is dominated by NH_4^+-N (Bernet et al., 2000). To obtain a better nitrogen removal, partial nitritation and autotrophic denitrification have to be performed in aerobic–anaerobic combined processes or sequencing batch reactors, but normally resulting in a high cost (Meng et al., 2015). Furthermore, autotrophic nitrification and denitrification would be inhibited when organic carbon source existed in wastewater because of their poor competition with heterotrophic bacteria (Ni et al., 2012). And the anaerobic condition required by autotrophic denitrifers would result in a poor COD removal (Chan et al., 2009). Though autotrophic denitrification has been extensively investigated, few reports on treating raw MFPW can be found up to now.

Microaerobic condition, identified by a dissolved oxygen (DO) of 0.3–1.0 mg/L, is a transitional state between anaerobic and aerobic conditions, and allows anaerobic and aerobic bacteria to coexist in a single activated sludge process (Hu et al., 2005; Zitomer, 1998). Microaerobic biological treatment technology has been proved feasible in treating domestic wastewater with low operating cost and less excess sludge produced (Chu et al., 2006; Zheng and Cui, 2012; Zitomer, 1998). But few researches on treating livestock and poultry wastewater were reported (Chu et al., 2006; Chuang et al., 2005; Hu et al., 2005). In previous research, an upflow microaerobic sludge reactor (UMSR) has been developed to treat raw MFPW without supply of extra carbon source (Meng et al., 2015). With a C/N ratio of about 0.84 in the wastewater and operated at a TN loading rate of 1.10 kg/(m^3 d), the average COD, NH_4^+-N and TN removal in the UMSR reached 0.72, 0.76 and 0.94 kg/(m^3 d), respectively. It was found that all anaerobic fermentation bacteria, ammonia-oxidizing bacteria (AOB), heterotrophic denitrifiers and autotrophic denitrifiers could dominate the UMSR (Meng et al., 2016). This result suggested that the proportion and activity of each functional bacteria in the inocula would affect the startup time and performance of the UMSR. Though the significant impact of seed sludge on microbial community structure, startup and pollutant removal in various biological processes have been extensively investigated, few researches on microaerobic processes could be found (Cao et al., 2013).

In view of the wide availability, anaerobic activated sludge (AnaS) and aerobic activated sludge (AerS) were collected as inocula to start up two UMSRs, respectively, in the present study. Effect of the inocula on the reactors' performance within the startup processes was evaluated. To get a comprehensive insight into the biological mechanism for the effect of the seed sludge on the microaerobic treatment processes, the microbial community structure in the two reactors was also investigated using Illumina Miseq platform.

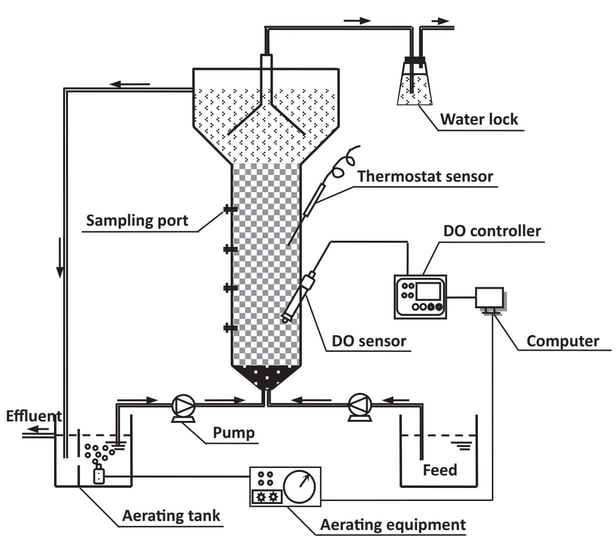

Fig. 1. Schematic representation of the lab-scale UMSR.

2. Materials and methods

2.1. Microaerobic treatment processes

To investigate the effect of AnaS and AerS as inocula on the startup of microaerobic treatment process treating MFPW, two UMSRs were constructed in the same structure. As illustrated in Fig. 1, each of the UMSR was a 0.5-meter-high plexiglass column with a working volume of 4.9 L. A 0.5 L circular cone was attached to the bottom of the column. A 3 L solid–liquid–gas separator was designed on the top of the column and the off-gas was discharged after a water lock. Four sampling ports were at 100 mm away from the bottom of the solid–liquid–gas separator. The piggery wastewater was introduced into the reactor by a peristaltic pump. The effluent was collected by a 10 L tank. Part of the effluent was aerated to a DO of about 3.0 mg/L and then recirculated into the reactor at a reflux ratio of 45:1 to create an internal microaerobic environment with a DO less than 1.0 mg/L. DO in the reactor was detected by an on-line monitoring instrument and used to control the aeration in the aerating tank. The two reactors were operated parallel and the internal temperatures were kept at the same 35 ± 1 °C by a temperature controller.

2.2. Wastewater and inoculums

Wastewater fed to the two UMSRs was the same raw MFPW collected from a local pig farm in Harbin, China. The quality of the wastewater fluctuated following the breeding seasonality. The average concentration of COD, NH_4^+-N, NO_2^--N, NO_3^--N, total nitrogen (TN) and pH was 307, 299.7, 0.1, 1.0, 366.9 mg/L and 8.0, respectively. One of the two UMSRs (marked as R1) was seeded by anaerobic activated sludge collected from an upflow anaerobic sludge bed (UASB) treating raw piggery wastewater in the State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, China. The other UMSR (marked as R2) was seeded by aerobic activated sludge from a domestic wastewater

Table 1
Stages and operating parameters of the two UMSRs.

Stage	day	Dilution ratio[a] (v/v)	pH	NH_4^+-N (mg/L)	NO_2^--N (mg/L)	NO_3^--N (mg/L)	TN (mg/L)	COD (mg/L)	NLR[b] (kg/(m^3 d))	OLR[c] (kg/(m^3 d))
1	1–49	3	7.6 ± 0.2	107.1 ± 11.4	0.3 ± 0.2	1.5 ± 0.5	132.9 ± 14.0	116 ± 19	0.40 ± 0.04	0.35 ± 0.06
2	50–94	1	7.9 ± 0.2	209.7 ± 16.7	0.2 ± 0.2	0.7 ± 0.6	256.8 ± 20.4	213 ± 26	0.77 ± 0.06	0.64 ± 0.08
3	95–161	0	8.0 ± 0.1	299.7 ± 16.4	0.1 ± 0.1	1.0 ± 0.3	366.9 ± 19.9	307 ± 35	1.10 ± 0.06	0.92 ± 0.11

[a] The ratio of dilution water to raw wastewater in terms of volume.
[b] Nitrogen loading rate in terms of TN.
[c] Organic loading rate in terms of COD.