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Start-up of a full-scale SNAD-MBBR process for treating sludge digester liquor

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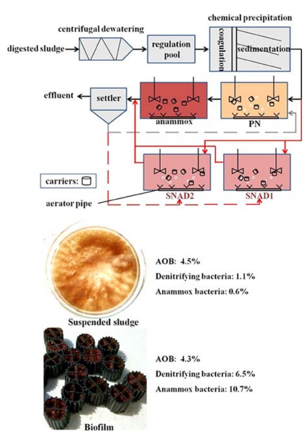
HIGHLIGHTS

- Anammox process is established by inoculating suspended NOB and anammox biofilm.
- SNAD-MBBR for treating the sludge digester liquor is started up successfully.
- Efficient cooperation among different microbial groups was developed in SNAD-MBBR.
- Proportions of various microbial groups in suspended sludge and biofilm are analysed.
- The segregation of different microbial groups ensures stable and efficient operation.

GRAPHICAL ABSTRACT



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ABSTRACT

A simultaneous partial nitrification, anammox and denitrification (SNAD) process was started up successfully to treat sludge digester liquor in a full-scale moving bed biofilm reactor (MBBR). This reactor treated up to 530 kg N/d with a nitrogen removal efficiency of 70%. During the start-up period, efficient and stable partial nitrification was attained by controlling the concentration of DO (0.3–0.5 mg/L), free ammonia (0.6–8.2 mg/L) and free nitrous acid (0.03–1.20 mg/L). The full-scale anammox reactor (832 m^3) took about 240 days to start up successfully after inoculation with nitrifying sludge and a small amount of anammox sludge. The preformation of anammox biofilm in the pilot-scale MBBR played a vital role in the fast start-up of the full-scale anammox MBBR. An average nitrogen removal rate of 0.41 kg $N/m^3/d$ was achieved. In the SNAD reactor, high-throughput sequencing techniques revealed that the anammox bacteria in the biofilm accounted for a higher proportion than in the suspended sludge, indicating that the carriers effectively protected the anammox from washout. This study provides valuable experience for treatment of wastewater with low carbon-to-nitrogen ratio.

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1. Introduction

With the rapid increase of the number and size of urban sewage treatment plants worldwide, the treatment of urban sewage sludge has become a severe environmental problem [1]. Urban sludge anaerobic digestion technology has been widely used for sludge stabilization treatment, and has potential for both energy recovery and emissions reduction [2,3]. However, the treatment of sludge digester liquor with high ammonium and low carbon-to-nitrogen ratio (C/N), created during the dewatering of digested sludge, is troublesome. During the digestion process, methane is generated from organic matter and nitrogen from the cells of dead microorganisms is released. The ammonium nitrogen produced during sludge digestion remains in the sludge dewatering filtrate. Often, the concentration of ammonium nitrogen in the sludge digester liquor is as high as 500–2000 mg/L [4]. In a sludge treatment plant (Dalian, China), the input materials of the anaerobic digestive system contained excess sludge, landfill leachate, and kitchen waste. The excess sludge accounted for more than 80% of the input materials. The dry matter content of the input materials was 8–12%. The concentration of ammonium in the sludge digester liquor fluctuated from 1460 to 1750 mg/L, and was mainly associated with the amount of landfill leachate in the system.

The sludge digester liquor is normally recycled into the influent of a wastewater treatment plant (WWTP), which causes significant internal nitrogen loading of the wastewater treatment system. This causes a corresponding increase in the investment and operation cost [5]. However, due to the high concentration of ammonium, it is not effective to treat the sludge digester liquor directly in the main wastewater treatment and purification process. It has been suggested that a side-stream biological treatment could be efficient and cost-effective for treatment of sludge digester liquor [6,7]. At present, there are three major side-stream biological treatments for sludge-digestion liquor: CANON process [8], SHARON-anammox process [9], partial nitrification/denitrification process [10] and DEMON process [11]. After side-stream biological treatment, the nitrogen loading to the wastewater treatment system was reduced and the WWTP could be operated more effectively and economically.

In a previous study, the feasibility of biological treatment of sludge digester liquor in this plant using the partial nitrification-anammox process was verified in a pilot-scale reactor [12]. Accordingly, in this study, a full-scale SNAD (simultaneous partial nitrification, anammox and denitrification)-MBBR (moving bed biofilm reactor) process was established as a side-stream biological process to treat the sludge digester liquor [13,14]. Compared to previous biological treatment processes, the SNAD process has the advantage of reducing the effect of organic inhibition on anammox activity, thereby improving the total nitrogen removal rate (NRR) and simultaneously removing carbon and nitrogen. The MBBRs incorporate benefits provided by both activated sludge and fixed film processes, which are able to develop suitable conditions for partial nitrification and anammox process [15]. In addition, the formation of anammox biofilm on the carriers increased the sludge retention time, which was conductive to the growth of anammox bacteria and to faster start-up of the anammox reactor [16].

In this study, the operating conditions needed for a stable partial nitrification process were investigated. An effective method for fast startup of the full-scale anammox process was determined. A feasible scheme for operation of the SNAD process for the treatment of sludge digester liquor was put forward. In the SNAD reactor, the biological communities and species proportions in the suspended sludge and biofilm were analysed using high-throughput sequencing.

2. Material and methods

2.1. Seed sludge

The activated sludge samples used for the acclimation and enrichment of ammonium oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) were collected from the Dalian Dongtai Xiajiahe WWTP (Dalian, China), which has a nitrogen loading rate of 0.06–0.08 kg N/m^3/d. The anammox inoculum (shown in Fig. S1) was harvested from a pilot-scale anammox reactor with CSTR type (3.6 m^3) feeding of sludge digester liquor [12]. The reactor had an average NRR of 1.24 ± 0.02 kg N/m^3/d and the specific anammox activity (SAA) was 1.01 ± 0.03 kg N/kg VSS/d.

Table 1
Characteristics of the sludge digester liquor.

Items	Range	Average
COD (mg/L)	500–800	658
BOD_5 (mg/L)	158–253	229
NH_4^+-N (mg/L)	1460–1750	1550
NO_2^--N (mg/L)	0.3–2.2	1.2
NO_3^--N (mg/L)	1.1–2.3	1.8
PO_4^{3-}-P(mg/L)	15.1–23.3	18.7
Inorganic carbon	200–230	208
Suspended solids (mg/L)	730–1055	815
pH	8.2–8.4	8.3
Alkalinity (mg/L)	5620–6230	5850

2.2. Characteristics of the sludge digester liquor

The digester liquor originated from dewatering of the anaerobic digested sludge in a sludge treatment plant. During the dewatering process, polyacrylamide (about 0.4 g/L) was added to the sludge digestion effluent. After dewatering, the sludge digester liquor was turbid and black in colour. The typical water quality of the sludge digester liquor is indicated in Table 1. The metal-element content of the sludge digester liquor is presented in Table 2. Based on the low heavy-metal content and previous study [12], it can be inferred that there was no heavy metal biotoxicity to the microorganisms.

2.3. Flow scheme and reactor configuration

Based on previous studies [12,17], the startup of the SNAD process in this study was divided into two steps. Firstly, the tandem-type partial nitrification-anammox (PN/A) process was started up to support the proliferation of anammox bacteria. Secondly, the integrated SNAD process was started. The flow scheme of the full-scale reactor is shown in Fig. 1A. First, a chemical precipitation process (coagulation and sedimentation process) was set to remove the suspended solids from the sludge digester liquor. The suspended solids level in the influent to the biochemical treatment unit was maintained at < 50 mg/L. The sludge digester liquor was fed into the partial nitrification (PN) process to produce an effluent favourable for anammox [18]. After successful start-up of the PN/A process and cultivation of sufficient anammox biomass, the nitrosation sludge and anammox sludge were mixed to initiate the SNAD process for further nitrogen removal. After side-stream biological treatment, the sludge digester liquor flowed into the

Table 2
Metal elements content analysis of the sludge digester liquor.

Items	Content (mg/L sludge digestion liquor)
Fe	0.50
As	0.02
Pb	0.03
Cu	Not detected
Mn	Not detected
B	Not detected
Hg	< 0.001
Cr	Not detected
Cd	< 0.002

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