Comparison between a submerged membrane bioreactor and a conventional activated sludge system on treating ammonia-bearing inorganic wastewater

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Abstract

A submerged membrane bioreactor (SMBR) and a conventional activated sludge system (CAS) were compared in parallel over a period of 210 days on treating synthetic ammonia-bearing inorganic wastewater under similar conditions. Except for a short period of pH control failure, almost complete conversion of $\text{NH}_4^+ - \text{N}$ to $\text{NO}_3^- - \text{N}$ was constantly achieved over an $\text{NH}_4^+ - \text{N}$ concentration range from 180 to 1300 mg l^{-1} at a hydraulic retention time (HRT) of 24 h in the SMBR, compared to an average conversion ratio of 95.0% in the CAS. Scanning electron micrographs (SEMs) demonstrated the accumulation of extracellular polymeric substances (EPSs) in the SMBR. Ubiquinone-8 (UQ-8), followed by UQ-10, UQ-7 and UQ-9, was the dominant ubiquinone in both the systems. The dominant menaquinone in the SMBR was menaquinone-6 (MK-6), while that in the CAS was MK-7, indicating that some differences existed between the two systems in terms of microbial community structure. Soluble microbial products (SMPs) tended to accumulate, and then biodegrade in SMBR.

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1. Introduction

Lithoautotrophic nitrification, the sequential transformation of NH_4^+ via NO_2^- to NO_3^- , is typically catalyzed by two phylogenetically distinct groups of bacteria, i.e., the ammonia- and nitrite-oxidizing bacteria. Nitrifiers have been characterized by low growth rates and poor yields, and nitrification is generally

a rate-limiting step in a biological nitrogen removal process. Therefore, a major difficulty in biological nitrogen removal has been to maintain adequate levels of nitrifiers in the aeration tank. For this purpose, large aeration tanks have to be constructed to ensure a long sludge retention time (SRT) to retain nitrifiers in the conventional biological nitrogen removal process. SMBR, in which the absolute retention of all microorganisms could be realized through membrane interception (Kishino et al., 1995; Muller and Stouthamer, 1995), makes it possible to have adequate nitrifiers in the biological treatment system.

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SMBR has already been demonstrated to be very useful for nitrogen removal (Suwa et al., 1992; Chiemchaisri et al., 1992; Takao et al., 2001; Rosenberger et al., 2002). However, previous studies mainly focused on nitrogen removal performance of the SMBR. Little studies on nitrogen removal have been conducted by operating SMBR and CAS working in parallel under similar conditions, and no direct comparison of the two systems was done from the viewpoint of microbial characteristics.

The objective of this study was to clarify the differences between SMBR and CAS in terms of nitrification performance and microbial characteristics by operating the two systems in parallel over a long period (210 days). The two systems were only fed with synthetic ammonia-bearing inorganic wastewater to delete the factors unrelated with nitrification. An extensive comparison of the mixed liquor, sludge and effluent of both the systems was performed by investigating various chemical, biological and physical parameters.

2. Results and discussion

2.1. Nitrification performance of SMBR and CAS

Nitrification performance of the two systems is shown in Fig. 1A and B, respectively. With the in-

crease of volumetric NH_4^+-N loading rate from 0.18 to 1.30 kg NH_4^+-N per m^{-3} per day by raising the influent NH_4^+-N , almost complete conversion (>99%) of NH_4^+-N to NO_3^--N was attained in the SMBR except for a short period of pH control failure. The nitrification performance of the CAS, on the other hand, became deteriorated on hiking the influent NH_4^+-N concentration on days 95 and 136, respectively. Especially in the later case, it took more than a month for the system to restore stable nitrification performance. Even under stable operation conditions, the conversion of NH_4^+-N to NO_3^--N was between 95 and 97%.

During the whole period of 210 days, the MLSS in the SMBR increased gradually from 2100 to 5500 mg l^{-1} , and the MLSS in the CAS increased from 2000 to 3700 mg l^{-1} . It is believed that the high sludge concentration retained in the SMBR contributed to the stable nitrification performance of the system.

2.2. Microbial aspects of the two systems

Fig. 2 shows SEM photos of sludge from the two systems at different times. Rod- and oval-shaped bacteria and characteristic clusters of nitrifying bacteria could be distinctly identified from photos on day 40. There was no apparent difference in morphology be-

Fig. 1. Variation of nitrogen compounds over the operation time. (A) SMBR and (B) CAS.

Fig. 2. Scanning electron micrograph indicating the spatial distribution of EPS and cell clusters over operation time in SMBR and CAS. (A1) The 40th day in the CAS; (A2) the 103rd day in the CAS; (B1) the 40th day in the SMBR; and (B2) the 103rd day in the SMBR

tween the two systems. However, with the prolongation of operation, microbes were gradually covered by EPS in the SMBR, and it was difficult to identify the microbial morphology clearly on day 103. Morphology of biomass in the CAS, on the other hand, was still clearly observed on day 103. EPS has been considered to be one of the main reasons for membrane fouling (Hoddson et al., 1993; Nagaoka et al., 1996). So, it is important to purge sludge from the SMBR to prevent the accumulation of EPS.

The number of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and heterotrophic bacteria

were determined by the most probable number (MPN) method as shown in Table 1. The number of nitrifiers and heterotrophic bacteria in the two systems increased with the prolongation of operation time. It is interesting that a small amount of heterotrophic bacteria existed in both the systems although only inorganic wastewater was fed. It is estimated that the heterotrophic bacteria were responsible for the decomposition of dead cells and EPS.

2.3. SMP of the two systems

Fig. 3 shows variations of SMP in terms of total organic carbon (TOC) in supernatant liquor and the effluent of the two systems. Gradual increase of TOC in the supernatant was observed in both the systems in the first 120 days. Then, the TOC in the SMBR supernatant began to decrease while that in the CAS system remained almost constant. The decrease of TOC in the SMBR supernatant was possibly caused by biodegradation. The interception ability of membrane made it possible to retain SMP degradation bacteria in the system. The TOC in the SMBR supernatant began to be lower than that in the CAS supernatant from day 170 due to biodegradation of SMP.

2.4. Microbial chemotaxonomy of two systems by microbial respiratory quinones

The microbial community structures of the two systems were qualitatively analyzed on day 180 by microbial respiratory quinones (Gao et al., 2003). The dominant ubiquinone was UQ-8 followed by UQ-10, UQ-7 and UQ-9 in both the systems. According to previous reports (Hiraishi, 1988), UQ-8 may represent *Comamonas* sp., certain members of *Pseudomonas* sp. and *Alcaligenes* sp., and UQ-10 was

Table 1
Variation of nitrifiers and heterotrophic bacteria in mixed liquors of SMBR and CAS

Number of days	SMBR (1081 ⁻¹ mixed liquor)		CAS (1081 ⁻¹ mixed liquor)	
	Nitrifiers ^a	Heterotrophic bacteria	Nitrifiers ^a	Heterotrophic bacteria
50	4.3	0.00026	0.91	0.00016
90	13.47	0.00038	2.65	0.00021
110	17.36	0.00043	3.92	0.00028
150	24.23	0.000467	8.33	0.00031
170	26.80	0.000545	9.87	0.00033

^a Data represent the sum of ammonia- and nitrite-oxidizing bacteria.

Fig. 3. Comparison of TOC in the supernatant liquor and the effluent between SMBR and CAS.

reported to be present in *Protomonas* sp. and *Paracoccus* sp. The dominant menaquinone in the SMBR was MK-6 followed by MK-7, MK-8, MK-8(H₂), MK-9(H₂), MK-9, MK-10 and MK-7(H₂). The dominant menaquinone in the CAS, however, was MK-7 followed by MK-8(H₂), MK-6, MK-8, MK-9, MK-9(H₂) and MK-7(H₂). *Flavobacterium* sp. and *Cytophaga* sp. contain MK-6 as a major quinone component, and MK-7 is often found in *Flavobacterium* sp., *Cytophaga* sp. *Bacillus* sp. and *Staphylococcus* sp. These results demonstrated that the two systems only had some minor differences in terms of microbial community structure. The meaning of the minor differences in microbial community to nitrification performance, however, requires further studies.

2.5. Physical characteristics of sludge from the two systems

Physical characteristics of sludge from the two systems were compared on day 135. For SMBR, particles in the size range of 50–200 μm in diameter were about 72% in volume, and about 20% particles had a diameter of less than 50 μm . On the other hand, in the CAS system, 58% particles were in the size range of 50–200 μm , and 23% particles had a diameter larger than 200 μm . The smaller particle size in SMBR was mainly due to violent current turbulence that aeration

produced under the membrane module (Liu, 2002). The sludge index (SVI) for the SMBR was determined as $70 \pm 10 \text{ ml g}^{-1}$, while the SVI for the CAS was only $50 \pm 15 \text{ ml g}^{-1}$.

3. Conclusions

The SMBR, which contained larger numbers of nitrifiers, was more effective and stable than the CAS in treating synthetic ammonia-bearing inorganic wastewater. SMP tended to accumulate, and then biodegraded in the SMBR. Periodical purging of sludge from SMBR is necessary to prevent the accumulation of EPS, which may cause the fouling of membrane. For both the systems, UQ-8, followed by UQ-10, UQ-7 and UQ-9, was the dominant ubiquinone. The dominant menaquinones, however, were different in the two systems, indicating that some differences in terms of microbial community structure existed between the two systems. Sludge particle size in SMBR was smaller than that in CAS.

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