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Comparison of the operational characteristics between a nitrifying membrane bioreactor and a pre-denitrification membrane bioreactor process

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ABSTRACT

A single submerged membrane bioreactor (MBR) for nitrification of ammonium and a pre-denitrification MBR process for total nitrogen (TN) removal were investigated in comparison. A single nitrifying MBR was fed with synthetic ammonium wastewater of up to 900 mgN/l without organics so that the MBR was maintained as a pure nitrifying system. A high nitrifying capacity around 1.8 kgNH_4-N/m^3/day was achieved while keeping the ammonium oxidation rate above 98%. Sludge volume index (SVI) gradually decreased down to less than 50 indicating good settleability of nitrifying sludge. The increase of suction pressure was less than 5 cm Hg over 7-months of operation. TN removal efficiency was determined in a pre-denitrification configuration with an anoxic reactor. Synthetic wastewater of 1200 mgCOD/l and 200 mgN/l was fed to the system at loads of 2.4 kgCOD/m^3/day and 0.4 kgN/m^3/day, respectively. As the internal recycle ratio from aerobic to anoxic zone increased from 2 to 6, TN removal efficiency was enhanced from 70 ± 9 to 89 ± 3%. With the sludge concentration of around 12,000 mg/l, SVI was highly fluctuated from 60 to 350 indicating the partial deterioration of sludge settleability. The suction pressure after 8 months of operation increased to above 10 cm Hg which is higher than that in a single nitrifying MBR. The concentration of extracellular polymeric substances (EPS), especially for carbohydrate content, was higher in the operation of a pre-denitrification MBR process than in a single nitrifying MBR. It is likely that the sludge characteristic such as settleability is related with membrane fouling but, further extensive study is needed. The performance of a pre-denitrification MBR process was also verified with real petrochemical nitrogen wastewater.

1. Introduction

Conventional activated sludge (CAS) process still has problems for the purpose of nitrogen removal. It is mainly caused from difficulties in maintaining a proper level of nitrifying bacteria within the process since nitrifiers are characterized by low growth rates and poor yields. Thus, nitrification is generally a rate-limiting step in a biological nitrogen removal (BNR) process [1]. Several modified versions of aerobic process with separate anoxic zones are practically being used for nitrogen removal but, the treatment efficiency is relatively low due to the low-efficiency of gravitational settler. In order to address those problems, membrane bioreactor (MBR) process has been suggested as a promising alternative to the CAS process [2–4]. The complete solid/liquid separation by membrane allows the operation at much higher sludge concentration and the growth of slow-growing nitrifiers which would not wash out by the membrane exclusion. Therefore, stable nitrification is possible as long as the growth environment such as oxygen concentration is suitable for nitrifiers. Another advantage of using membrane is the high quality of effluent obtained from membrane filtration. The effluent produced by the MBR can either be directly used for water reuse application or fed to the reverse osmosis process without any further treatment [5].

Earlier reports showed that submerged MBRs were efficient for nitrogen removal [3,4,6] but, studies focusing on operational characteristics and stability such as sludge settling property and the change of suction pressure in nitrogen-removing MBRs are limited. In MBR processes reported for TN removal, the pre-denitrification configurations with anoxic zone were preferred since the endogenous use of wastewater carbon is possible [2,7]. In this study, two MBR systems, a single nitrifying MBR for high-rate nitrification and a pre-denitrification MBR process with an anoxic reactor, were operated in comparison. Ammonium wastewater excluding organics was supplied to a nitrifying MBR while a pre-denitrification MBR process was fed with usual balanced wastewater including carbon source. It is likely that sludge compositions affecting the operational characteristics are different between both MBR operations. Although much work has been carried out to

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investigate the filtration characteristics in MBRs operated for the removal of organics and/or TN, investigations on a pure nitrifying MBR or the comparisons with the TN-removing MBR processes are limited to the best of our knowledge. The objective of this study was to monitor the operation of a nitrifying MBR, especially in terms of sludge characteristics potentially affecting the membrane filtration performance, and also to compare with the pre-denitrification MBR process. Sludge volume index (SVI) and extracellular polymeric substances (EPS) in both systems were compared, and the increases of suction pressure were monitored to find the correlations between those operational variables. Over 7–8 months of operation, the nitrifying capacity and TN removal efficiency of MBR systems were also determined.

2. Materials and methods

2.1. Construction of membrane bioreactor system

A rectangular type reactor with an 8-l working volume, in which one element of hollow fiber membrane (0.1 μm pore size, 0.2 m^2, Mitsubishi Rayon Co., Japan) was submerged, was used as an aerobic reactor. The pressure gauge was installed in order to monitor the variation of the suction pressure between membrane and suction pump. Air was supplied through a coarse bubble diffuser located underneath the membrane module. The diffuser was a 1.5-cm diameter tube with 1 mm openings, so that coarse bubbles could be produced. The air functions in supplying the required oxygen to the microorganisms and cleaning the membrane surface.

Fig. 1 shows the configuration of pre-denitrification MBR process, in which the anoxic reactor was excluded in the operation of a single nitrifying MBR. The working volume of aerobic and anoxic reactor was initially 8 and 12 l so that total operating volume of pre-denitrification process was 20 l. To maintain a constant level in the reactors, a peristaltic pump feeding the influent and a level sensor were used in an anoxic reactor. By gravity, the overflowed sludge was led to aerobic reactor and recycled to the anoxic reactor.

2.2. Operating conditions

MBR was seeded with sewage sludge or petrochemical WWTP sludge acclimated to synthetic nitrogen wastewater. The composition of synthetic ammonium wastewater for a single nitrifying MBR operation was as follows: NH_4Cl, 100–900 mgN/l; $NaHCO_3$ (as $CaCO_3$) 3–7.1 mg/mgN; $MgSO_4 \cdot 7H_2O$ 33 mg/l; $CaCl_2 \cdot 2H_2O$ 20 mg/l; KH_2PO_4 60 mg/l; K_2HPO_4 80 mg/l; $FeCl_3 \cdot 6H_2O$ 3 mg/l; $MnSO_4 \cdot H_2O$ 10 mg/l; NaCl 25 mg/l. For a pre-denitrification MBR operation, carbonaceous components were supplemented either to provide organics for denitrification (basis: COD 1200 mg/l, TN 200 mg/l): glucose 808 mg/l; glutamic acid 345 mg/l; CH_3COONH_4 265 mg/l; NH_4Cl 460 mg/l. The petrochemical wastewater, collected from the effluent of secondary clarifier in petrochemical WWTP, was also used to verify further the performance of MBR. NH_4^+-N and TN concentration of that effluent was 440 ± 19 mgN/l and 471 ± 22 mgN/l, respectively. COD concentration was less than 40 mg/l so acetic acid was supplemented during the operation. In all cases, the temperature was kept at ambient condition of 20–27 °C. The pH was controlled by using 1 M sodium bicarbonate at 7.5.

Since the intermittent suction showed better performance in maintaining stable membrane filtration [8], the permeate was extracted by a suction pump operated periodically in a 10 min cycle (8 min on and 2 min off). The hydraulic retention time was fixed at 12 h. SRT and MLSS concentration were controlled by the intermittent wasting of excess sludge. In a single nitrifying MBR, SRT was fixed at 60 days while it was determined in the range of 20–30 days according to the ratio of wasting sludge in a pre-denitrification MBR operation. The amount of wasting sludge was varied since the sludge concentration was targeted to be maintained at less than 15,000 mg/l in a pre-denitrification MBR process. The sludge recycle ratio over influent flow rate (*Q*) was varied during the operation. Dissolved oxygen (DO) in the aerobic reactor was not controlled and the air flow rate was fixed in the range of 15–20 l/min.

2.3. Analytical methods

COD concentration was measured by Hach Laboratory method (DR/4000, Hach, USA). MLSS and SVI were measured according to the standard methods [9]. Ammonium (NH_4^+-N) concentration was measured by a Nesslerization method by reading absorbance at 425 nm. Nitrite (NO_2^--N) and nitrate (NO_3^--N) were determined by ion chromatography (Basic IC, Metrohm, Switzerland). DO, pH, and membrane flux were monitored daily. Extraction of EPS from sludge flocs was done by heat treatment method. Then, the carbohydrate and protein levels of EPS were analyzed using phenol–sulfuric acid method [10] and protein assay kit (P5656, Sigma) using BSA as standard.

3. Results and discussion

3.1. Nitrification in a single nitrifying MBR

After a MBR was seeded with sludge, the enrichment and acclimation to develop nitrifying sludge was carried out by

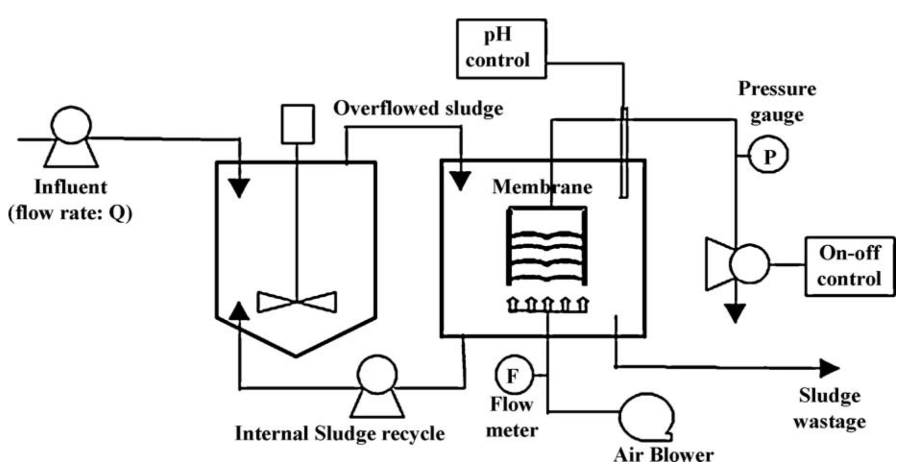

Fig. 1. Scheme of submerged membrane bioreactor system.