Bioresource Technology 100 (2009) 1048–1054

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Enhanced biological nutrient removal using MUCT–MBR system

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ARTICLE INFO

Article history:
Received 18 April 2008
Received in revised form 23 July 2008
Accepted 24 July 2008
Available online 2 September 2008

Keywords:
Membrane bioreactor
Denitrifying phosphorus removal
Short-cut nitrification
Simultaneous nitrification and denitrification (SND)

ABSTRACT

Biological nutrient removal was investigated in a combined modified University of Cape Town and membrane bioreactor system. When the influent nutrient mass ratio (COD/TN/TP) was 28.5/5.1/1 to 28.5/7.2/1, average removal efficiencies of COD, TN and TP were 90%, 81.6%, 75.2%. Obvious denitrifying phosphorus removal occurred with C/N ratio 3.98. When nitrite was the main electron acceptor, the ratio of denitrifying phosphate uptake to the total phosphate uptake were 99.8% and the sludge yield was 0.28 kg VSS/kg COD; when nitrate was the main electron acceptor, the ratio was 92% and the yield was 0.32 kg VSS/kg COD. In case of nitrite, the system not only kept TP and TN removal at 89.1% and 82.2%, but also ensured less sludge production. Batch tests showed that the proportion of denitrifying phosphorus-accumulating organisms in the total phosphorus-accumulating organisms in the system was higher than 80%.

1. Introduction

Eutrophication, mainly caused by nitrogen and phosphorus, has become one of the most urgent problems to be solved. In conventional biological nutrient removal systems, both N and P removal require COD, which is often the limiting substrate in the incoming wastewater. Making best use of the available COD for N and P removal is one of the objectives of current research and development efforts in biological nutrient removal (BNR) design and operation.

The occurrence of denitrifying phosphorus-accumulating organisms (DPAOs) is a great progress in treating deficient carbon source influent. Differ from phosphorus-accumulating organisms (PAOs), DPAOs can utilize nitrite or nitrate instead of oxygen as electron acceptors to remove phosphate under anoxic condition (Hu et al., 2002; Gilda et al., 2007; Kuba et al., 1993). Thus COD can been utilized simultaneously for both N and P removal (Lee et al., 2001; Merzouki et al., 2005; Satoshi et al., 2006). It has been reported that for the same amount of nutrient removal, the use of DPAOs was beneficial to reduced COD consumption (Kuba et al., 1996), lower aeration cost (Henze et al., 1999) and less sludge production (Sorm et al., 1997).

Denitrifying phosphorus removal requires an aerobic phase for the nitrification to provide nitrate or nitrite as an electron acceptor. According to whether PAOs coexist with nitrifiers, denitrifying phosphorus removal processes can be classified into single- and two-sludge systems. In the two-sludge system, nitrifiers are separated from PAOs and the conditions are favorable for successful removal of nitrogen and phosphorus (Hao et al., 2001; Liu et al., 2008). However, the system requires extra units. Furthermore, some ammonium surviving in the anaerobic sludge flows out directly and deteriorates the effluent quality. The University of Cape Town (UCT) process is one of typical single-sludge system. In this process, sludge is recycled to anoxic tank and the mixture is continuously returned from anoxic tank to anaerobic tank, which could weaken the effects of nitrogen oxide (NO_x^-) on phosphate release. Modified University of Cape Town (MUCT) process is proposed based on UCT. Both absolute denitrification and good performance of denitrifying dephosphatation are hopeful to realize when influent C/N ratio is favorable.

In recent years, more and more membrane bioreactors (MBR) have been used in wastewater treatment for advantages over the conventional activated sludge processes, such as the complete solid–liquid separation, high effluent quality, absolute control of solids and hydraulic retention times, preventing failure of biological systems due to biomass loss and/or bulking and maintenance of high mixed liquor suspended solids (MLSS) in the reactor. The combinations of MBR have been used for treating various types of wastewater with good removal performance of organic matter, nitrogen and phosphorus (Burhanettin et al., 2007; Chae and Shin, 2007; Kim et al., 2008).

MUCT-type process was combined with MBR and an innovative MUCT–MBR system was developed in our study. With the same

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doi:10.1016/j.biortech.2008.07.045

cyclic mode of sludge to MUCT-type process, five reactors tanks were replaced by two reactors in this system. It was hopeful to enhance biological nutrient removal, reduce COD consumption and sludge production.

The objectives of this study were to test the performance of nutrient removal in MUCT–MBR system. In addition, sludge characteristics, C/N ratio, sludge yield and membrane fouling were investigated.

2. Methods

2.1. Reactors set-up and operation

An experimental apparatus which consisted of Ra and Rb with 11 L working volume was used in this study. The water was fed to Ra through an electromagnetic valve controlled by a timer. A balance-box with a float-ball valve was used to control the water level of Ra. Agitators were installed to keep the biomass in suspension. Air diffusers were installed underneath the membrane module of Rb with a rotameter controlling aeration intensity. The membrane module used in Rb was a hollow fibre membrane made of polyethylene (DAIKI, Japan) with a pore size of 0.1 μm and a filtration area of 0.15 m^2.

Ra was operated under alternating anaerobic and anoxic conditions and Rb was operated under alternating anoxic and aerobic conditions. In the first 10 min of anaerobic phase, 2 L wastewater was fed into Ra. During this phase, PAOs released phosphate, took up biodegradable organic carbon substrates and stored them as PHAs. At the same time, Rb was in aerobic phase, aerating and draining 2 L water through membrane module. In this phase, some PAOs utilized oxygen as electron acceptors to absorb partial phosphate and nitrifying bacteria transformed ammonia into nitrate and nitrite, which could be used as electron acceptors for subsequent anoxic phosphorus uptake. At the end of anaerobic phase of Ra (aerobic phase of Rb), 2 L mixed liquid was pumped from Rb to Ra (R1) and 6 L mixed liquid was transferred from Ra to Rb (T) by peristaltic pump in 12 min. After that, both reactors went into anoxic phase and DPAOs utilized nitrate or nitrite as electron acceptors to achieve denitrifying phosphorus removal. For sludge return, 2 L mixed liquid was pumped from Rb to Ra (R2) at the end of anoxic phase in 12 min. The cycle mode was consisted of 77 min anaerobic (including filling 10 min), 67 min anoxic (including 12 min T/R1 and 12 min R2) and 77 min aerobic.

In the experiment, solid retention time (SRT) was maintained at 15 days by wasting sludge mixed liquor at the end of aerobic stage. Temperature was controlled at about 25 °C. The influent pH was kept at 8.0 ± 0.2 and $NaHCO_3$ was used as the buffer to prevent alkalinity dropping for nitrification. Diversion ratio (defined as the ratio between the volume transferred from Ra to Rb (T) per cycle and the volume of influent) was 3. Reflux ratio (defined as the ratio between the volume recycled from Rb to Ra per cycle and the volume of influent) was 2 (including R1 and R2). The experiment operated continuously for about five months and contained three phases. The operational parameters of the two reactors are shown in Table 1.

Table 1
Operational parameters of the two reactors

Phase (C/N)	I (5.58)		II (3.98)		III (3.98)	
	A	B	A	B	A	B
HRT (h)	13.2	13.2	11.4	13.2	11.4	13.2
Volume (L)	11	11	9.5	11	9.5	11
Air flow rate (L/h)	–	100	–	100	–	150

2.2. Inocula and feed medium

Inoculation sludge (MLVSS/MLSS 0.52) was obtained from the feedback sludge tank of the municipal wastewater treatment plant located in Ling-shui town of Dalian and pre-incubated before being put into the reactor. Synthetic wastewater fed to the reactor consisted of sucrose, NH_4Cl, K_2HPO_4, KH_2PO_4 and mineral solution (containing $MgSO_4 \cdot 7H_2O$, $CaCl_2 \cdot 2H_2O$, $FeSO_4 \cdot 2H_2O$ and $CoCl_2$). Influent contained COD, 213–300 mg/L; TP, 8.2–11.3 mg/L; and TN, 41.3–69.2 mg/L.

2.3. Analytical methods

Ammonia nitrogen (NH_4^+—N), nitrate nitrogen (NO_3^-—N), nitrite nitrogen (NO_2^-—N), total phosphorus (TP) and COD were analyzed according to the standard methods for the examination of water and wastewater (APHA). The total nitrogen (TN) concentration was determined with a total organic carbon analyzer (TOC-V_{CPH}, Shimadzu). pH was measured by a pH meter (PB-10, Sartorius, Germany).

2.4. Experimental procedures

2.4.1. General experiments

These experiments were conducted for investigating the removal of nitrogen, phosphorus and COD. Effluent of one cycle was collected in a beaker and the mixture was used for analysis.

2.4.2. Cyclic studies

Cyclic study was conducted to sample mixture of a cyclic from Ra (at 0, 20, 40, 60, 77, 89, 109 and 132 min) and Rb (at 89, 109, 132, 144, 164, 184, 204 and 221 min). It could clarify the transformation of various pollutions during the cycle and provide information for adjusting the operation parameters.

2.4.3. Determination of TP content of the sludge

The mixture was taken from Ra at 0, 77, 89, 132 min and Rb at 89, 132, 144, 221 min to analyze TP concentration of supernatant and that of sludge-supernatant compound. MLVSS was determined simultaneously. The TP content of the sludge was calculated as follows:

$$\text{TP content of sludge } [\text{mg (g VSS)}^{-1}] = \frac{[\text{TP}]_c - [\text{TP}]_s}{\text{MLVSS}}$$

where $[TP]_c$ represents TP concentration of sludge-supernatant compound. $[TP]_s$ represents TP concentration of supernatant.

2.4.4. Batch experiments

In order to investigate PAOs and DPAOs in more detail, batch experiments (including Ba and Bb) were carried out using the methods reported by Wachtmeister et al. (1997). Ba: the sludge was transferred from Ra to a sealed vessel at the end of anoxic phase. It was incubated anaerobically with excess sucrose for 90 min to increase the PHB stored by sludge. Then the sludge was divided into two parts. One part was exposed to aerobic condition to measure aerobic phosphorus uptake rate (APUR) and the other part was exposed to anoxic condition to measure anoxic phosphorus uptake rate (NPUR). Phosphate uptake rate was evaluated from the slop of the line describing the linear decrease in phosphate concentration. Based on the assumption of the DPAO sludge having a nearly identical phosphorus uptake under anoxic and aerobic conditions, the ratio of NPUR to APUR was used to analyze the proportion of DPAOs in PAOs (Hu et al., 2003; Meinhold et al., 1999; Satoshi et al., 2006). Bb: the sludge was transferred from Rb to a sealed vessel at the end of aerobic phase. Other approaches were the same as Ba.