Chinese Journal of Chemical Engineering 23 (2015) 303–308

Contents lists available at ScienceDirect

Chinese Journal of Chemical Engineering

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

Energy, Resources and Environmental Technology

Simultaneous removal of nitrogen and phosphorus from swine wastewater in a sequencing batch biofilm reactor☆

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ARTICLE INFO

Article history:
Received 19 April 2013
Received in revised form 22 December 2013
Accepted 12 January 2014
Available online 26 September 2014

Keywords:
Sequencing batch biofilm reactor
Swine wastewater
Simultaneous nitrogen and phosphorus removal

ABSTRACT

In this study, the performance of a sequencing batch biofilm reactor (SBBR) for removal of nitrogen and phosphorus from swine wastewater was evaluated. The replacement rate of wastewater was set at 12.5% throughout the experiment. The anaerobic and aerobic times were 3 h and 7 h, respectively, and the dissolved oxygen concentration of the aerobic phase was about 3.95 $mg \cdot L^{-1}$. The SBBR process demonstrated good performance in treating swine wastewater. The percentage removal of total chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), and total phosphorus (TP) was 98.2%, 95.7%, 95.6%, and 96.2% at effluent concentrations of COD 85.6 $mg \cdot L^{-1}$, NH_4^+-N 35.22 $mg \cdot L^{-1}$, TN 44.64 $mg \cdot L^{-1}$, and TP 1.13 $mg \cdot L^{-1}$, respectively. Simultaneous nitrification and denitrification phenomenon was observed. Further improvement in removal efficiency of NH_4^+-N and TN occurred at COD/TN ratio of 11:1, with effluent concentrations at NH_4^+-N 18.5 $mg \cdot L^{-1}$ and TN 34 $mg \cdot L^{-1}$, while no such improvement in COD and TP removal was found. Microbial electron microscopy analysis showed that the filler surface was covered with a thick biofilm, forming an anaerobic–aerobic microenvironment and facilitating the removal of nitrogen, phosphorus and organic matters. A long-term experiment (15 weeks) showed that stable removal efficiency for N and P could be achieved in the SBBR system.

1. Introduction

Since the 1990s, the growth of large-scale industrial livestock enterprises has solved the livestock supply problem and promoted rural community economic development. However, this industrial growth is also responsible for severe environmental pollution. Generally, swine wastewater contains high levels of nutrient pollutants such as nitrogen and phosphorus, which contribute to eutrophication of water bodies [1,2]. Therefore, swine wastewater treatment technologies are in demand for effective nutrient pollution control. Currently, swine wastewater is mainly treated by combined anaerobic/aerobic processes, which are effective for the removal of chemical oxygen demand (COD) and suspended solids (SS), confirmed by pilot study and engineering applications, but fail to remove nitrogen and phosphorus. More reliable and economic treatment processes are needed [3].

The sequencing batch biofilm reactor (SBBR) is a biological process based on the sequencing batch reactor (SBR) and utilizes microorganisms (attached to a plastic carrier) to treat wastewater. As a new biological wastewater treatment process, SBBR has been widely studied and applied because of its prominent advantages such as more biomass and less sludge, simple and flexible operation, and good sewage treatment effect [4,5]. Fang and Chen conducted experiments to compare SBBR and SBR processes in treating slaughterhouse wastewater and showed that the outlet water quality with SBBR was better [6]. Jiang and Zhai tested the ability of the SBBR process to remove nitrogen and phosphorus simultaneously from domestic sewage, with the removal efficiencies for TP and TN at 84% and 80%, respectively, at dissolved oxygen (DO) concentration of 3.5 $mg \cdot L^{-1}$ and sludge retention time of 25 days [7]. Xiao *et al.* used the SBBR process to treat swine wastewater, with the removal of COD and NH_4^+-N at 92.8%–94.1% and 94.8%–96.1%, respectively, at a hydraulic retention time (HRT) of 10 days, temperature of 24–26 °C, and DO concentration less than 2.0 $mg \cdot L^{-1}$ [8], but they did not discuss the TP removal. The SBBR process combines the advantages of SBR process and biomass retention properties of attached biofilms and has been used for treating various types of wastewater, but few reports are on its application to remove nitrogen and phosphorus simultaneously from swine wastewater. The major objective of this study is to examine the factors influencing simultaneous removal of nitrogen and phosphorus from swine wastewater using SBBR and determine the optimal process parameters such as HRT, DO and COD/TN ratio.

2. Materials and Methods

2.1. Laboratory scale SBBR

Fig. 1 shows a lab-scale SBBR reactor in this study, with an internal diameter of 15 cm, a height of 55 cm, a total volume of 9.7 L, and a

☆ Supported by the Beijing Municipal Science and Technology Program (Z12110000 1512008).
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http://dx.doi.org/10.1016/j.cjche.2014.09.036
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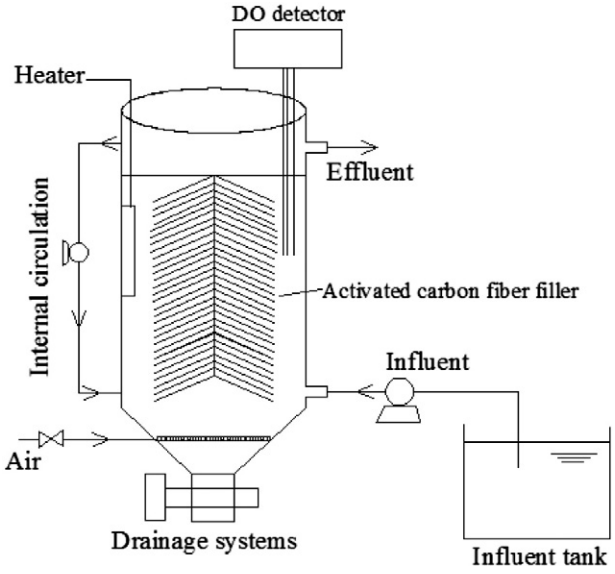

Fig. 1. A schematic diagram of SBBR.

working volume of 8.0 L. It was fabricated with Plexiglas material for easy observation of biofilm carriers and sludge in the reactor. The feed was introduced at the bottom of the reactor to achieve better mixing in the reaction. An activated carbon fiber filler was installed in the reactor, which is 40 cm in length and contains about 12000 carbon fiber threads. Tens of thousands of filaments were dispersed to form a huge surface area, and flexible carbon fiber yarns swung with the water in the reactor under the aeration condition, so that the mass transfer could be improved in the biofilm.

The reaction time for each stage in SBBR was controlled by a timer. The concentration of DO in the reactor was maintained by microporous aerators during the aerobic phase, and the anaerobic cycle was achieved through the circulation pump during the anaerobic phase. The controller was programmed to operate on a repeating 24 h cycle with a sub-program, and the output went to the operation of each controllable element. Temperature, which has a remarkable effect on the respiratory rate of microorganisms, was maintained between 25–30 °C in the experimental process to maintain high activity of microorganisms.

2.2. Wastewater

In this study, the swine wastewater was taken from a swine breeding farm of Tongzhou district in the suburbs of Beijing. It was allowed to settle for 6–12 h to remove some suspended solids. The collected swine wastewater was stored at 4 °C.

2.3. Reactor start-up and operation

The swine wastewater was instantly charged into the SBBR and drawn through the outlet after the completion of an operation cycle (20% water exchanged, 1.6 L). Table 1 shows the major characteristics of the swine wastewater. In the first stage of microbial culture, aerobic condition (DO > 2.0 $mg \cdot L^{-1}$) was maintained, and the original swine wastewater was diluted (with COD 470 $mg \cdot L^{-1}$, NH_4^+-N 85 $mg \cdot L^{-1}$, and TP 3.2 $mg \cdot L^{-1}$). Seed activated sludge taken from a sewage plant in Beijing was used for the SBBR setup. The activated sludge had mixed liquor suspended solids (MLSS) of 7568 $mg \cdot L^{-1}$ and mixed liquor volatile suspended solids (MLVSS) of 4762 $mg \cdot L^{-1}$, with the value of MLVSS/MLSS at 0.63. The SBBR was subsequently operated at an HRT of 24 h to obtain steady performance, and then the influent wastewater concentration was gradually increased until it equaled the original concentration. After 8 days of cultivation, significant biofilm formed on the carbon fiber threads in SBBR, and the percentage removal values of COD and NH_4^+-N were 73% and 62%, respectively. With microscopic examination, the biofilms were found to be mature.

Table 1
Characteristics of the swine wastewater used in this study

Parameter	Average/$mg \cdot L^{-1}$	Standard deviation/$mg \cdot L^{-1}$	Number of samples
COD	4684	332	14
NH_4^+-N	846	49	14
TN	1062	58	14
TP	31.9	2.4	14
NO_3^--N	<0.1	–	14
NO_2^--N	<0.1	–	14
SS	2080	610	14

The second stage was to nurture the phosphorus accumulating capacity of the system. The operation strategy was: fill (5 min)–anaerobic phase (1.5 h)–aeration phase (6 h)–settle (20 min)–draw (5 min). As shown in Fig. 2, after 65 days of cultivation, effluent concentrations of COD and TP decreased to 99.2 and 3.11 $mg \cdot L^{-1}$, respectively, indicating that the phosphorus accumulating bacteria domestication was completed.

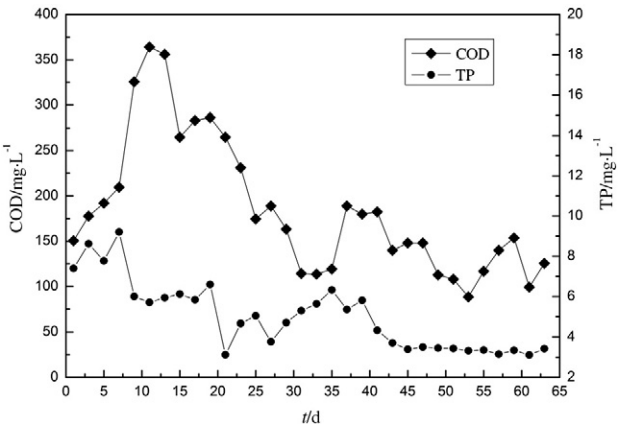

Fig. 2. COD and TP data of phosphate accumulating bacteria domestication stage.

2.4. Scanning electron microscopy

After 45 days of cultivation, a sponge cuboid was extracted from the carbon fiber thread in SBBR, and scanning electron microscopy (SEM) was used to visualize the large amount of microorganisms in the biofilm. The biofilm sample was suspended in a 0.1 $mol \cdot L^{-1}$ phosphate buffer solution (pH 7.4) for 24 h at room temperature. Then, the sample was dehydrated by six consecutive extractions in ethanol/water solutions at increasing ratios (from 10 to 100). Finally, the sample was freeze dried, gold-coated by a sputter, and examined by SEM (S-4700, Japan) operated at 20 kV.

2.5. Analytical methods

The concentrations of COD, NH_4^+-N, NO_3^--N, NO_2^--N, TN, TP, MLSS and SS were measured according to the Water and Wastewater Monitoring Analysis Method [9]. The pH, oxidation reduction potential (ORP), and temperature were tested by using a HANA HI8424 pH/ORP/T tester. The DO was measured continuously online by using a DO detector (HACH sc100, USA). The microorganisms were observed through an Olympus CX31 type biological microscope.