Desalination 250 (2010) 781–786

Contents lists available at ScienceDirect

Desalination

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

Performance of the combined SMBR–IVCW system for wastewater treatment ☆

En-Rong Xiao, Wei Liang, Feng He, Shui-Ping Cheng, Zhen-Bin Wu *

State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, No.7 Donghu South Road, Wuhan, 430072, China

ARTICLE INFO

Article history:
Accepted 5 November 2008
Available online 17 October 2009

Keywords:
SMBR–IVCW
Submerged MBR
Integrated vertical-flow constructed wetland
HLR, HRT

ABSTRACT

A new SMBR–IVCW system, which combined a submerged MBR (SMBR) unit and an integrated vertical-flow constructed wetland (IVCW) unit, was applied to treat the high strength integrated wastewater. The study showed that this system of biological and ecological combination was stable and good at improving the quality and efficiency of polishing wastewater. Six runs under different HRT combinations were carried out in order to obtain the better purification performance of the SMBR–IVCW system. The results indicated that the better HRT combination was 7.7 h for SMBR and 11.52 h for IVCW. In such condition, the concentrations of COD, ammonia and TP in the final effluent were 11.0, 0.086 and 0.44 mg L^{-1}, respectively, which reached the Class III of the national environmental quality standards for surface water in China. In fact, the HRT of the two units had great effect on the purification efficiency and investment cost. By regulating the ratio of HRT between these two units, the optimum operation conditions could be obtained to reach the double wins of high purification and low costs. In the SMBR–IVCW system, the SMBR unit acted as the secondary treatment, contributing to removing the organics and nitrification. While the IVCW unit was more like as the tertiary treatment, contributing to the denitrification and further dephosphorization.

1. Introduction

Membrane bioreactor (MBR) technology has drawn more and more attention in the wastewater treatment market due to its good effluent water quality and short footprint [1]. Because it combines the advantage of conventional active sludge (CAS) and the predominance of membrane separation [2,3], this technology is especially fit for the high concentration or hardly degradable wastewater. As an aerobic biological treatment method, MBR can achieve good quality of effluent with low concentrations of TSS (total suspended solid), COD, ammonia and small quantity of microbes [4], but with poor removal rates of nitrogen and phosphorus [5,6]. Being an ecological wastewater treatment technology, constructed wetland (CW) was very practical with the low cost and easy management [7]. Its high removal rates for nitrogen and phosphorus were assumed to make up for the shortcoming of MBR [8,9]. Hence, the combined technology of MBR and CW, which was applied to treat the high concentration wastewater, may be a good try. In this study, the combination of submerged MBR (SMBR) [10] and integrated vertical CW (IVCW) [11] was applied to treat the high concentration wastewater, which could supply for a new mode for the wastewater treatment. The aim of this study was to obtain the best hydraulic retention time (HRT) combination and try to make clear the contribution of SMBR and IVCW.

2. Materials and methods

2.1. Experimental set-ups

A pilot-scale SMBR–IVCW system was set up according to Fig. 1. For SMBR unit, a hollow fiber membrane module made from polyvinylidene fluoride (PVDF) was submerged in a reactor with 320 L effective volume. The main characteristics of membrane module were as follows. The membrane surface was 4 m^2; the nominal pore size was 0.2 μm; the inner/outer diameter was 0.6 mm/1.0 mm, and the membrane molecular weight cut off was 500 ku. Two baffles, at the side of the membrane module, divided the reactor into an up-flow area and two down-flow areas. And the aeration pipe under the module supplied the continuous oxygen and crossflow. As for IVCW, it consisted of two chambers, which were separated by a wall but connected at the bottom. The two chambers, which had the same area of 1 m^2 (1 m × 1 m), were filled with the fine sand with a diameter of 0.5–2 mm. The depths of sand layer in the down-flow chamber and up-flow chamber were 55 cm and 45 cm, respectively. *Canna indica* and *Acorus calamus* were respectively planted in the down-flow chamber and up-flow chamber, at the density of 27 individuals/m^2. The wastewater flew into the SMBR from the water tank, degraded by active sludge, passed through down-flow and up-flow chamber in turn and finally flew out from the outlet.

2.2. Experiment design

SMBR was operated in a relatively steady state according to the previous research [12]. The mixed liquid suspended solid (MLSS) was

☆ Presented at the Conference on Membranes in Drinking and Industrial Water Production, 20–24 October 2008, Toulouse, France.

* Corresponding author. Tel.: +86 27 68780045; fax: +86 27 68780675.
E-mail address: erxiao@ihb.ac.cn (Zhen-Bin Wu).

0011-9164/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.desal.2008.11.041

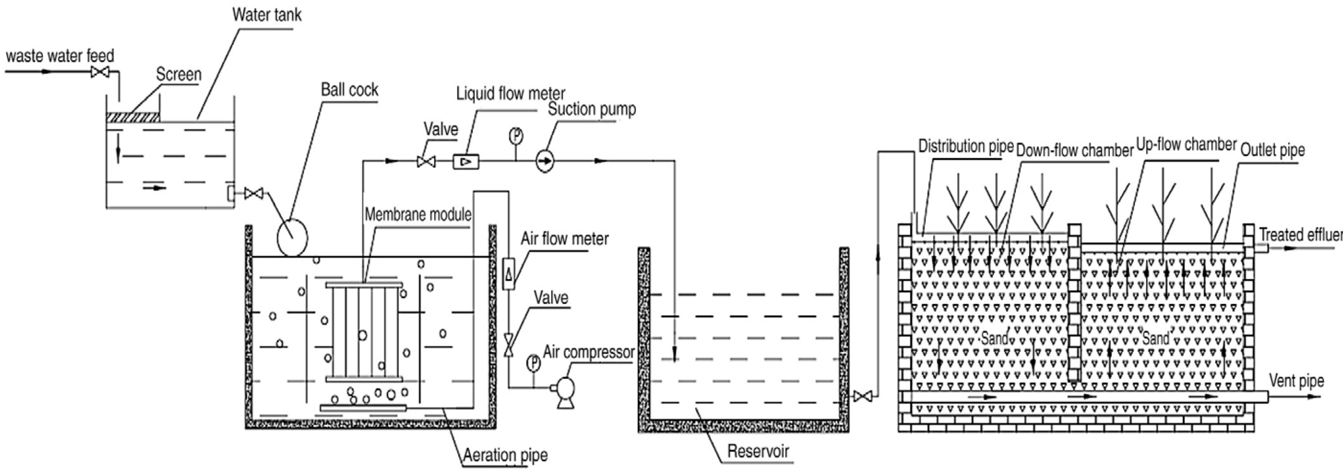

Fig. 1. Schematic diagram of the SMBR–IVCW set-up.

7.0 ± 0.5 g/L; the aeration rate was 6 ± 0.5 m^3/h; the ratio of pumping time to break time was 4:1; the ratio of up-flow area to down-flow area was 1.7:1, and the sludge retention time (SRT) was 25–30 d. The influent flew into the SMBR intermittently by manually controlling the valve. When the water level in the reactor was up to the highest, the influent valve was turned off, and when the water level was 15 cm lower than the top of baffles, this valve turned on. When the water level was up to the highest again, the valve turned off again. The interval between two turning offs of the valve was about 2 to 4 h, which depended on the output. SMBR ran three cycles every day in such fashion and got continuous influent in the residual time. IVCW unit also got intermittently influent at the frequency of four times a day, and the interval of each time was 4 h.

The SMBR–IVCW system was operated at the environment temperature of 25–35°C. The whole experiment consisted of six groups (Table 1). In each group, this system was run steadily for a month under each combined hydraulic retention time (HRT), meanwhile, the concentrations of influent were maintained relatively stable. The influent was the mixture of domestic wastewater and some proportional nutrient substances.

The influent and effluent from the SMBR unit and IVCW unit were measured every three days during the steady running, and the means of each influent and effluent were used to represent the inflow and outflow for the whole day respectively.

2.3. Analytical methods

The main water quality indexes of physical and chemical, such as COD, TP, TN, ammonia of the influent and effluent were measured in accordance with Chinese NEPA Standard Methods [13]. The MLSS was online measured by the Total Suspended Solids Interface Level Analyzer (ROYCE 711). The oxygen uptake rate (OUR) and the specific OUR (SOUR) were measured according to the method [14]. The difference among the removal efficiencies of the SMBR–IVCW in different HRT was assessed using One-way ANOVA. The statistical analysis was carried out with Statistical Package for the Social Science (SPSS 13.0) software. Statistical significance test was evaluated at 95% confidence interval. Correlations and differences were considered significant at $p \leq 0.05$.

Table 1
Summary of the SMBR–IVCW system operating conditions.

G	SMBR		IVCW		SMBR–IVCW
	HLR (L/d)	HRT_1 (h)	HLR (mm d^{-1})	HRT_2[a] (h)	HRT[b] (h)
1	500	15.4	125	34.56	49.96
2	750	10.2	187.5	23.04	33.24
3	1000	7.7	250	17.28	24.98
4	1250	6.2	250	17.28	23.43
5	1500	5.1	187.5	23.04	28.14
6	1000	7.7	375	11.52	19.22

[a] The porosity of the substrate in IVCW was assumed as 0.36.
[b] $HRT = HRT_1 + HRT_2$.

3. Results and discussion

3.1. The total decontamination of the SMBR–IVCW system

Fig. 2 showed the concentration changes of COD, TP, TN and ammonia in the influent, effluent from SMBR unit and effluent from the IVCW unit of the SMBR–IVCW system respectively during the whole experimental period.

It can be found that the SMBR–IVCW system has steady removal for COD (Fig. 2(a)), TP (Fig. 2(b)) and ammonia (Fig. 2(d)) except TN (Fig. 2(c)) in different HRT combinations. For statistics analysis, the influent concentration of the 6 groups does not show significant differences ($p > 0.05$) for all the water quality parameters mentioned above. The average influent concentrations of COD, TP, TN and ammonia were 1008.08 ± 63.60 mg L^{-1}, 5.76 ± 0.38 mg L^{-1}, 95.22 ± 3.22 mg L^{-1} and 62.10 ± 2.60 mg L^{-1} respectively ($n = 60$). The effluent concentrations were relatively low after passing through the SMBR–IVCW system. The COD kept under 25 mg L^{-1} for all the groups. The TP remained less than 0.1 mg L^{-1} for Groups 1, 2, 3 and 6, and under 0.2 mg L^{-1} for Groups 4 and 5. The ammonia maintained under 0.5 mg L^{-1} for Groups 1, 2 and 6, and under 0.8 mg L^{-1} for Groups 3, 4 and 5. But, TN in the final effluent showed obvious undulation from 5 mg L^{-1} to 17 mg L^{-1}. The total removal rates of COD, TP and ammonia of the SMBR–IVCW system were over 98%, 96%, 99% and 80% respectively for all the groups. In general, the SMBR–IVCW system indicated a good capacity of anti-hydraulic-impact and high effective decontamination.

3.2. The effect of HRT on the performance of SMBR–IVCW system

HRT is one of the important design parameters to determinate the purification efficient, treatment capacity and even capital cost both for biological treatment way and ecological treatment way [15,16]. Fig. 3 showed the relationship between the HRT and the removal rate of the SMBR–IVCW system.

According to the experimental design (Table 1), the total HRT decreased from Group 1 to Group 3 as well as the HRT_1 (HRT of the SMBR unit) and HRT_2 (HRT of the IVCW unit). Taking the total