*Desalination and Water Treatment*
www.deswater.com
9 (2009) 259–262
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# Enhanced biological phosphorus removal in a novel sequencing membrane bioreactor with gravitational filtration (GFS-MBR)

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Received 15 September 2008; Accepted 30 August 2009

**ABSTRACT**

A **novel** sequencing membrane bioreactor with gravitational filtration (GFS-MBR) was developed and its performance of biological phosphorus and nitrogen removal of the urban sewage was also studied in this paper. The GFS-MBR was operated in a 12-h cycle—anaerobic fill (0.5h), anaerobic mixing (4.5h), aerobic phase(5h), settle(1h) and decant(1h). As the averaged COD, $NH_4^+$-N, TP and TN in the influent were 284 mg/L, 13.9 mg/L, 1.92 mg/L and 18.63 mg/L, respectively, the averaged removal efficiencies were 95.2%, 95%, 96.4% and 50.5%, respectively. The results indicate that the ratio of influent COD/TP is the key factor for achieving enhanced biological phosphorus removal (EBPR) with full sludge age in long-term operation (92 days, 184 cycles) in the GFS-MBR, and as the influent COD/TP was 148, the effluent TP was 70 μg/L. In addition, the membrane fouling was caused mainly by inorganic matters.

***Keywords:*** Batch processing; Enhanced biological phosphorus removal (EBPR); Gravitational filtration; Hollow fibres; Membrane bioreactors(MBR); Wastewater treatment

## 1. Introduction

The sequencing batch reactor (SBR) is simple to operate and very flexible for combining nitrogen and phosphorus removal, and suitable for the small-scale wastewater treatment [1]. And the membrane bioreactor (MBR) has been gaining great attention in sewage treatment and reuse as the membrane filtration promises a complete solid-liquid separation, prevents failure of biological systems due to biomass loss and/or bulking and maintains high mixed liquor suspended solids (MLSS) in the reactor [2]. However, the techniques till now for removal of phosphorus are not desirable. Recent studies on wastewater treatment using MBR have focused on nutrient removal [3-7]. A new sequencing membrane bioreactor with gravitational filtration system (GFS-MBR) was developed focusing on biological phosphorus and nitrogen removal, and its performance was mainly discussed in this paper.

## 2. Material and methods

### 2.1. Test system

The experimental setup is shown as Figure 1. The new gravitational filtration typed sequencing membrane bioreactor (GFS-MBR) mainly consists of a SBR and a membrane module. The SBR is made of PVC with an available capability of 20L. Microporous diffusers were installed at both bottoms of SBR and membrane module. The membrane module was made of PVDF(pore size: 0.25μm), and the total membrane surface area was 0.5m$^2$.

### 2.2. Analysis

The influent flow, pH, and temperature in GFS-MBR were measured daily. COD, $NH_4^+$-N, total nitrogen (TN), and total phosphorus (TP) in both influent and effluent,

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

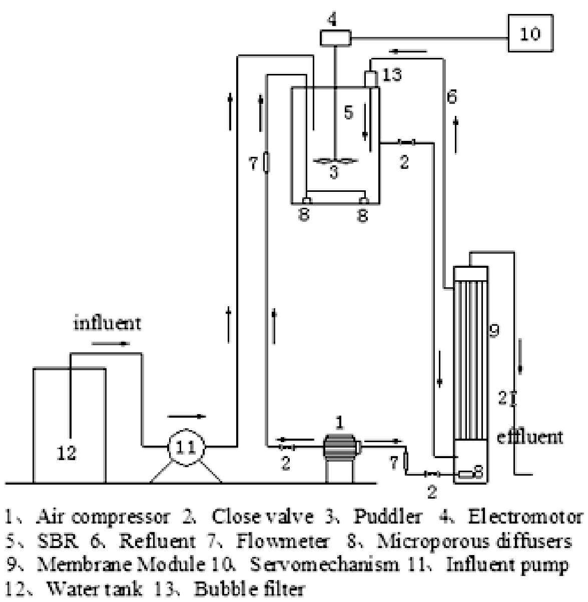


Fig. 1. Schematic of the lab-scale GFS-MBR setup.

MLSS and MLVSS were regularly analyzed according to Standard Methods [8]. In this study, $NO_3^-$-N was calculated as the minus of TN, $NH_4^+$-N and $NO_2^-$-N.

$BOD_5$ was determined by BOD Trak™ (Hach Company, U.S.A.), the wastewater samples were digested by HACH—COD digester (Hach Company, U.S.A.), COD, $NH_4^+$-N, $NO_2^-$-N and TP was detected by DR4000U spectrophotometer (Hach Company, U.S.A.). Dissolved oxygen (DO) was measured daily by WTW−OXii330i dissolved oxygen meter (WTW Company, German). TN was measured by Multi N/C2100 meter (Analytik Jena AG, German). The pH value was monitored by a pH meter (Orion-828, U.S.A).

### *2.3. Raw wastewater*

The urban sewage was from the sewer system of students' dormitory, canteen, the university administration building and the sewage discharged from laboratories, Wuhan University of Technology. The characteristics during the experimental operation are shown in Table1.

### *2.4. Operation condition*

GFS-MBR was originally inoculated with the excess sludge of Shahu Wastewater Treatment Plant (WWTP), Wuhan, Hubei, China. The influent flow was low at the beginning and was gradually increased along with activated sludge culture for about 20 days. The GFS-MBR was operated in a 12-h cycle—anaerobic fill (0.5h), anaerobic mixing (4.5h), aerobic phase(5h), settle(1h) and decant(1h). 10L wastewater could be treated once a cycle. For the aim to prevent the membrane from being polluted, the membrane module was aerated at the decant phase. Besides sampling, there is no excess sludge discharged.

The experiment was carried out for 44 days from the autumn to the winter and 48 days from the spring to the summer in 2006. During the operation, MLSS was 8–10g/L, HRT was 12 hrs, the organic load ranged 0.4–1.37kgCOD/kgMLSS·d, the temperature 5❑–31❑, pH 6.8–8.0, and the membrane specific flux 26–33L/$m^2$ h.

## 3. Results and discussion

### *3.1. Overall performance of the experimental GFS-MBR setup*

The effect of various contamination removed by the GFS-MBR system was also showed in Table 1. The TN removal in the GFS-MBR system was 50.5%, the removal efficiencies of other contamination were above 95%, and the effluent was coincident to the first class of Chinese national discharge standard for the sewage treatment plants.

### *3.2. The performance of enhanced biological phosphorus removal*

Figure 2 shows the removal effect of total phosphorus by GFS-MBR experimental setup during the

Table 1
Overall performance of the experimental GFS-MBR setup.

| Component | Influent ranged/(mg·$L^{-1}$) | Influent /(mg·$L^{-1}$)* | Effluent/(mg·$L^{-1}$)* | Removal (%)* |
|---|---|---|---|---|
| COD/(mg·$L^{-1}$) | 202–550 | 284 | 11 | 95.2 |
| $BOD_5$/(mg·$L^{-1}$) | 85–287 | - | - | - |
| TP/(mg·$L^{-1}$) | 1.25–3.28 | 1.92 | 0.07 | 96.4 |
| $NH_4^+$-N/(mg·$L^{-1}$) | 7.66–16.46 | 13.9 | 0.7 | 95.0 |
| $NO_2^-$-N/(mg·$L^{-1}$) | 0.01–0.07 | - | - | - |
| TN/(mg·$L^{-1}$) | 10.56–38.26 | 18.63 | 9.28 | 50.5 |
| pH | 6.5–7.5 | - | - | - |
| Temperature/❑ | 8–25 | - | - | - |

*Averaged value

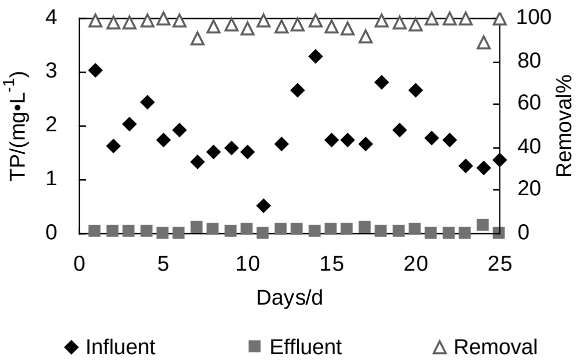


Fig. 2. The removal effect of total phosphorus in the GFS-MBR.

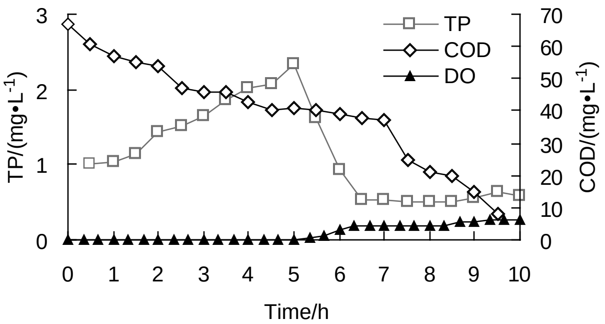


Fig. 3. The GFS-MBR profile of TP, COD and DO in a cycle(Day 75).

operation period (Partial data). When the concentration of total phosphorus was 0.54–3.28mg/L in influent, it was 0-0.13mg/L in the effluent. The results indicated a removal rate at the range of 89%–100% in this research.

Figure 3 shows the profile of TP, COD and DO in a typical cycle when the lab-scale setup operated stately. Figure 3 indicates that at the first 5 hours when the system was in anaerobic state, the phosphorus concentration in the mixed liquid was increasing gradually while the COD concentration was decreasing contrarily. In the anaerobic state, the phosphate accumulating organisms (PAOs) decomposed the accumulated phosphorus in the cells and degraded (or transformed) it into inorganic phosphorus then released it. Therefore, the phosphorus concentration of the mixed liquid in the reactor reached maximum 2.33mg/L at the end of anaerobic process and the COD concentration also reduced by 40.3%. At the following 5 hours aerobic process, the phosphorus concentration reduced rapidly to 0.5mg/L only in 90 minutes. At aerobic state, polyhydroxyalkanoate (PHA) in the cells was decomposed by PAOs, and the energy derived from this decomposing process partial supplied to PAOs to regenerate, the other partial energy supplied to PAOs to forwardly absorb phosphate in the wastewater, then gathered in the cells in the form of polyphosphorus, thus the phosphate was removed from the liquid. So the SBR

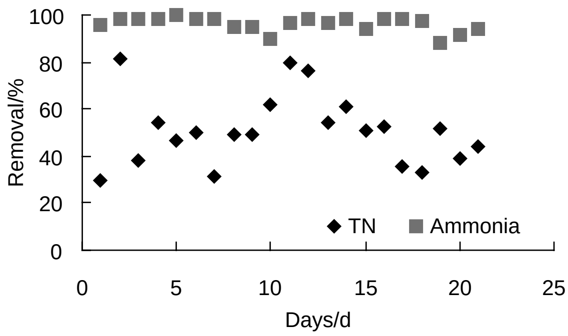


Fig. 4. TN and $NH_4^+$-N removal in the lab-scale GFS-MBR setup.

in GFS-MBR setup exhibited characteristic EBPR carbon and phosphorus transformations (complete anaerobic carbon uptake with concomitant inorganic P release and PHA synthesis, followed by aerobic inorganic P uptake), and produced high-TP-content sludge (2.0–2.9%, wt)[9].

The experiment setup operated with full sludge retention time for 92 days, and when the influent COD/TP was as high as 148, providing conditions for phosphorus removal bacteria in the anaerobic process to fully release phosphorus, and the effluent phosphorus concentration was only 70μg/L, the phosphorus removal rate as high as 96.4%. The results also indicated that the crucial factor of enhanced biological phosphorus removal was adequate organic substance at the anaerobic process.

### 3.3. The performance of Nitrogen removal

Figure 4 shows the removal effect of $NH_4^+$-N and TN by GFS-MBR during its operation period (partial data). The $NH_4^+$-N removal efficiency was 88.2%–99.9% during operation period, but the TN removal rate was only 29.5%–81.5%.

### 3.4. Membrane flux and fouling

At the steady state, suitable aeration technique was adopted to the membrane module, and the membrane specific flux was 26–33L/$m^2$·h in test. The sewage was treated and clarified by the SBR system so the organic load of membrane bioreactor was very low. At the same time, the aeration on the membrane could produced plenty tiny air bubbles that restrained small particulates from congregated on the membrane surface, alleviated the membrane fouling at a high extent. The result indicated the new process could effectively control the membrane fouling.

The membrane module which had operated 44 days and 48 days, respectively, was cleaned by 5% HCl and NaOH, respectively. The clean experiment indicated that the cleaning effect of HCl was better than NaOH, the membrane specific flux which membrane cleaned by HCl was increased from 12.5L/m$^2$·h to 38.5L/m$^2$·h, this data closed to the water flux value 41.6L/m$^2$·h, however the membrane specific flux which membrane cleaned by NaOH increased from 14.6L/m$^2$·h to 27.3 L/m$^2$·h, the cleaning effect of the membrane module with HCl solution is better than that with NaOH. This data indicated that the contamination on the surface of membrane was mainly inorganic salt.

## 4. Conclusions

The main conclusions from this investigation can be summarized as follows:

1. When HRT = 12h, the GFS-MBR influent COD, $NH_4^+$-N, TP and TN were 202~550 mg/L, 7.66~16.46 mg/L, 1.25~3.28 mg/L and 10.56~38.26 mg/L, respectively, the averaged removal efficiencies were 95.2%, 95%, 96.4% and 50.5%, respectively.
2. The results indicated that the ratio of influent COD/TP is the key factor for achieving enhanced biological phosphorus removal with no excess waste sludge discharged in long-term operation.
3. The GFS-MBR system could effectively control the membrane fouling and maintain a high membrane specific flux, the main membrane pollutant is inorganic matter and the cleaning effect of the membrane module with HCl solution is better than that with NaOH.

## Acknowledgements

Financial support from National Natural Science Foundation of China (50878173) is greatly appreciated.

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