

# Domestic wastewater reclamation by submerged membrane bioreactor with high concentration powdered activated carbon for stream restoration

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**Abstract** This study focuses on the practical application of high concentration powdered activated carbon coupled membrane bio-reactor to domestic wastewater reclamation. The study was conducted in three parts, such as analysis of secondary domestic wastewater effluent, design and operation parameter evaluation and reclaimed water quality estimation for stream restoration. The organic concentration was 25.2–80.2 mgCOD<sub>Cr</sub>/L for the effluent of three domestic wastewater treatment plants. Around 50–75% of the COD was low molecular substances less than 1,000 which were quite biodegradable. The sawdust PAC was estimated to be proper adsorbent for the organics in the secondary effluents. Its Freundlich constant, K value was 5.847 and 1/n, 0.36. Using a system consists of single reactor with high concentration PAC (80 g/L) and submerged hollow fiber MF membrane module with nominal pore size of 0.1 μm, design and operation parameters were obtained, such as HRT of the bioreactor (2.5 hr), PAC concentration (80 g/L), the initial flux (less than 0.5 m/day) and intermittent suction cycle (12 min. suction and 3 min. idling). Organic removal by the system was high enough to produce reclaimed water for urban stream restoration. The effluent organic concentration was at the level of 2 mg/L in terms of TOC (around 5 mg/L as COD<sub>Cr</sub>). Substances with molecular weight cut off < 1,000 were removed mostly by adsorption and biodegradation. Those above 1,000 were rejected at PAC cake layer on the membrane and gradually degraded by microorganisms during extended contact.

**Keywords** Adsorptions; biological powder activated carbon; membrane bioreactor; stream restoration; wastewater reclamation; water reuse

## Introduction

Wastewater reclamation and reuse has been recognized as important alternative for water resources preservation and water pollution control. Advances in wastewater treatment technologies have improved the capacity to produce reclaimed wastewater and more reliable cost effective technologies are needed for acquiring new water supplies and protecting existing water sources from pollution (Asano and Levine, 1998). Membrane bioreactor (MBR) becomes a center of recent research interests for wastewater reclamation because of its benefits, such as less space requirements, higher effluent quality in terms of organics and nutrients, disinfection effect and increased volumetric loading (Manem *et al.*, 1996; Adham *et al.*, 2001). Despite the excellence of MBR, many researches were conducted to promote the performance of MBR, such as effluent quality enhancement and membrane fouling control (Seo *et al.*, 2000, Choi *et al.*, 2002; Chang and Judd, 2002). PAC coupled membrane system has been introduced for enhanced removal of tracer organic matter by Adham *et al.* (1992) and Pirbazari *et al.* (1992). The process was developed to PAC coupled MBR which showed the evidence in refractory organic matter and virus from secondary effluent (Seo *et al.*, 1996, 2001). Greater sorption capacity of organic matter and enhanced microbial activity was observed with high concentration PAC in the MBR (Seo *et al.*, 1997, 2002). MBR with high concentration powdered activated carbon (HCPAC) could remove

the residual organics in secondary effluent by adsorption and biodegradation. The PAC can also prevent fouling of the membrane from organics and extra-cellular polymeric substances generated by microorganisms. Membrane has a role of barrier to separate the PAC and water. The added PAC could be retained in the reactor without replacement with flash one. In spite of the successive research on the HCPAC coupled MBR, a further study is required to establish design and operation parameters for practical application of the system. In this study a pilot scale investigation was conducted for real application of the system to produce reclaimed water for urban stream restoration. The system design and operation parameters as well as long term performance were also evaluated.

## Materials and method

### Experimental apparatus

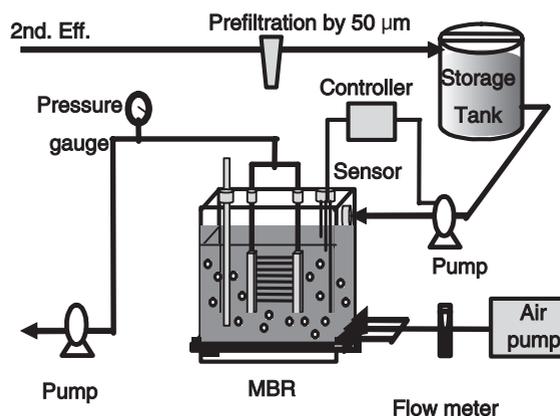
Figure 1 is the flow diagram of HAPAC-MBR system. A secondary effluent of domestic wastewater treatment plant was used as an influent which was introduced to the reactor after pre-filtration (pore size of 50  $\mu\text{m}$ ). Influent flow rate was controlled by level sensor set in the reactor with working volume of 180 L. 1.8 L of sludge (MLSS 3,000 mg/L) was added into the reactor with 80 g/L PAC at installed below the membrane module for aeration and prevention of excessive cake formation on membrane surface. Continuous monitoring was carried out at inlet and outlet of the system as well as bulk phase of the reactor. TOC and  $E_{260}$  were measured by TOC analyzer and UV Spectrophotometer.

### Membrane

As shown in Table 1, Membrane used for the study was hollow fiber MF membrane with nominal pore size 0.1 micron. The membrane was made of polyethylene(PE) with hydrophilic coating. The filtration area of the membrane module was 4  $\text{m}^2$  for pilot scale apparatus.

**Table 1** Membrane module characteristics

Parameter	Specification
Pore size	0.1 micron
Membrane material	Polyethylene (PE)
Surface characteristic	Hydrophilic (permanently)
Surface area	4 $\text{m}^2$



**Figure 1** Schematic diagram of HCPAC-MBR process

### Powdered activated carbon (PAC)

Three types of PAC (saw dust, coal, Coconut) were used to evaluate the adsorption capacity of the residual organic matter in the secondary effluent. The PAC was washed with pure water 7 times to remove impurities mixed in PAC before the adsorption test.

## Results and discussion

### Secondary effluent characteristics

Secondary effluent was analyzed for sewage and domestic wastewater treatment plants. The results are shown in Table 2. Although the secondary effluent quality varied depending on several parameters such as the influent quality, treatment process, and operational conditions of the treatment facility etc., the effluent was in the range of 15.4–42.7 mg/L as COD and 0.05–0.22 as  $E_{260}$  for sewage treatment plant. On the other hand the concentration was relatively high for domestic wastewater treatment plant showing 25.2–80.2 mg/L as COD and 0.13–0.49 as  $E_{260}$ .

The residual organics was characterized in terms of molecular weight distribution which was tested by UF stirred cell. 67.7–75.2% of COD was less than molecular weight cut off (MWCO) 500 for sewage treatment plant effluents. Similarly 65.4–72.1% of COD was less than 1,000 for domestic wastewater treatment effluents. This means that most of the secondary effluents contain organics of lower molecular substances and they are still biodegradable, which is different from the report that residual organic matter in the secondary effluent consists of hardly biodegradable substances (Murakami *et al.*, 1972)

### Design and operation parameters

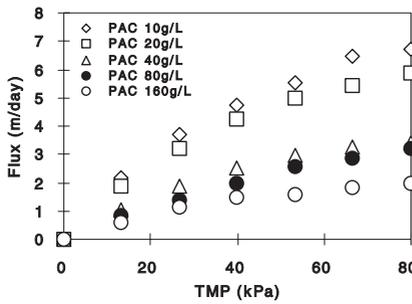
Design and operational parameters were estimated in Lab. Scale experiment. First adsorption isotherm tests were carried out for three types of PAC using secondary effluents. The test results are analyzed by Freundlich equation. Sawdust PAC had better adsorption capability for the residual organics than other two types of PAC in terms of Freundlich constants showing 0.09–0.36 and 3.531–6.677 for  $1/n$  and  $k$  value, respectively. Proper PAC concentration in the bioreactor was estimated by filtration resistance at different dosage of PAC, such as 10, 20, 40, 80 and 160 g/L in pure water. As shown in Figure 2, higher PAC concentration resulted in the reduced flux at the same trans-membrane pressure (TMP), which might be caused by the PAC cake resistance. Although the cake resistance is relatively higher at PAC 40 or 80 g/L than 10–20 g/L, 80 g/L of PAC was selected as the proper concentration in the bioreactor for long term operation (Kim *et al.*, 2000).

Intermittent suction filtration was adopted in the system. The suction interval was evaluated under following conditions; PAC 80 g/L with sludge inoculation, 5 L/min. air supply rate, water temperature 20°C and initial flux 1.1 m/d. From the test results shown in Figure 3, the suction/idle interval of 12 min/3 min was selected among various interval in terms of

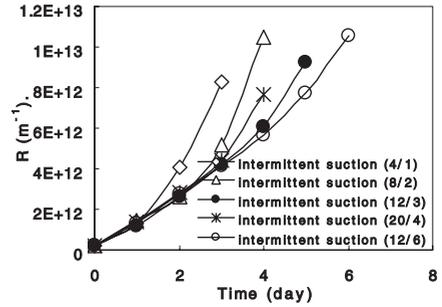
**Table 2** 2nd effluent characteristics

Parameter	2nd effluent	
	Sewage treatment plant	Domestic wastewater treatment plant
BOD (mg/L)	4.4–14.3	17.4–28.6
COD <sub>Cr</sub> (mg/L)	15.4–42.7	25.2–80.2
SS (mg/L)	2.8–16.6	10.2–20.0
T-P (mg/L)	0.64–1.76	2.75–3.85
T-N (mg/L)	6.74–23.22	17.59–29.19
NH <sub>3</sub> -N (mg/L)	0.23–0.80	0.91–11.39
$E_{260}$ *	0.050–0.221	0.131–0.486

\*: Absorbance at wave length 260 nm



**Figure 2** Flux variation by TMP at various PAC concentration



**Figure 3** Increase of filtration resistance at different intermittent suction interval

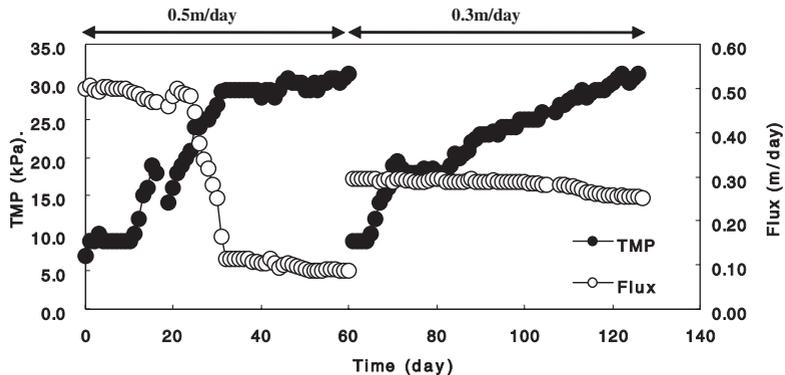
filtration resistance and filtration flow. In addition to the tests above, the organics in secondary effluent was contacted with activated sludge to check its biodegradability. More than 80% COD was removed in 2.4 h contact. Consequently hydraulic retention time 2–3 hour is enough to degrade the residual organics.

#### System performance of CHPAC-MBR

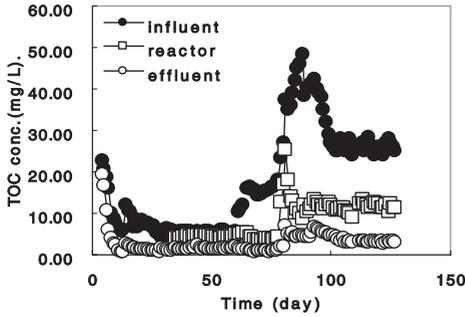
**Flux and TMP variation.** TMP variation was observed at different initial flux in pilot scale experimental apparatus and appeared in Figure 4. At the initial flux 0.5 m/d, the TMP was maintained at 9 kPa for 10 days. However rapid increase of the TMP was observed from 11th day and it reached plateau at 30 kPa with drastic flux decline. When the initial flux was controlled at 0.3 m/d, the TMP was stably maintained at 20 kPa without flux decline for 60 days.

Various resistances of the membrane were analyzed after 60 days operation at the initial flux 0.5 m/d. Total resistance,  $R_T$  could be divided into cake and gel layer resistance,  $R_c + R_g$ , and micro-pore plugging and membrane resistance,  $R_p + R_m$ . 93% of the total resistance,  $2.8 \times 10^{13} \text{m}^{-1}$  was caused by  $R_c + R_g$ ,  $2.6 \times 10^{13} \text{m}^{-1}$ . This means that the filtration resistance could be controlled by the PAC cake layer and the irreversible membrane fouling could be prevented by the PAC cake.

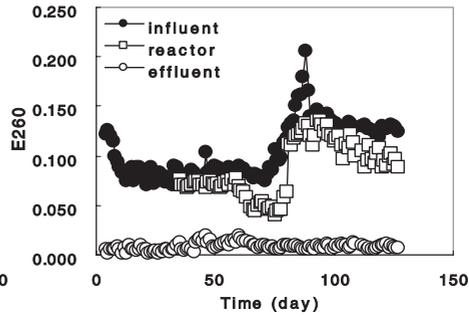
**Organic removal.** Figure 5 is the daily observation of TOC of influent and effluent, and bulk phase of the reactor. The TOC monitoring was started 4 days after operation of the system. Initially the organic removal might be accomplished by the PAC adsorption and breakthrough of adsorption must occur in 4 days operation. Afterward the biodegradation



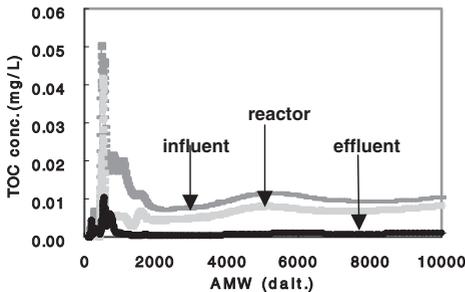
**Figure 4** Variations of TMP and flux of the membrane for semi-pilot plant



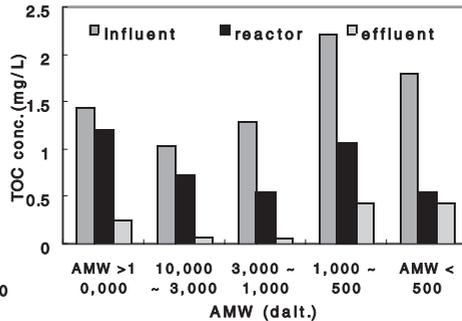
**Figure 5** Daily variation of TOC concentration



**Figure 6** Daily variation of  $E_{260}$



**Figure 7** Result of GPC analysis of samples at different stage of the system



**Figure 8** TOC variation at different stage of the system in terms of MW

starts after acclimation. From 10 days operation, the effluent TOC was stably maintained less than 2 mg/L for influent TOC concentration of 5–20 mg/L. This result was identified at batch test to remove TOC by membrane, PAC and biodegradation, respectively. MF with pore size of 0.1 micron could reject TOC only 26%. 74% of TOC was removed by fresh PAC adsorption and 83% of TOC by biodegradation in 2.4 h contact. From these results, it is obvious that the TOC removal is accomplished by the combination between PAC adsorption and biodegradation. Figure 6 shows the daily variation of  $E_{260}$  which is the index of hardly biodegradable organic substances. The removal  $E_{260}$  was quite different from the TOC. It must be removed by PAC adsorption at initial stage. However the removal efficient was stably maintained above 80% regardless its concentration in the reactor. Consequently it could be concluded that the hardly biodegradable organic matter is removed by PAC adsorption in the reactor and then degraded by microorganism at extended contact time.

Figure 7 shows the gel permeable chromatography (GPC) of the samples taken after 20 days operation at each stage of the system. On the basis of the chromatogram, TOC removal at each stage was expressed in terms of molecular weight distribution. Molecular weight of the samples is mainly distributed at around MWCO 500–1,000. Even if organics of MW greater than 2000 was existed at a certain portion for influent and bulk phase of the reactor, most of them were removed after membrane filtration. Consequently it was evaluated that lower molecular weight substances are removed by adsorption and biodegradation in the reactor while higher MW organics by the cake layer formed on the membrane surface.

## Conclusions

Following conclusions were obtained from the pilot scale study on the HCPAC-MBR for application to wastewater reclamation.

1. The secondary effluent contains residual organics 15.4–42.7 mg/L as COD and

- 0.05–0.2 as  $E_{260}$  for sewage treatment plant. While the concentration was relatively high for the effluent from domestic wastewater treatment plants showing 25.2–80.2 mg/L as COD and 0.13–0.49 as  $E_{260}$ . The molecular weight distribution of the organics was in less than MWCO 500–1,000.
2. Design and operation parameters were obtained, such as HRT 3 h, PAC concentration in the reactor 80 g/L, and intermittent suction interval 12 min. suction/3 min. idle.
  3. The operation flux 0.3 m/d was better than 0.5 m/d in terms of filtration resistance and stable operation of the system.
  4. Organic removal by the system was excellent producing the effluent quality less than 2 mg/L TOC which is enough to meet river water quality standard less than 6 mg/L as BOD.
  5. Hardly biodegradable organics could be removed by PAC adsorption and then by biodegradation at extended contact time. This could be explained by the GPC analysis and molecular weight distribution of the samples taken at each stage of the system.

### Acknowledgements

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