# Pilot scale study on a new membrane bioreactor hybrid system in municipal wastewater treatment

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**Abstract**

A pilot scale membrane bioreactor hybrid system (MBR-HS) was evaluated for municipal wastewater treatment. This novel system comprised of a granular activated carbon – sponge fluidized bed bioreactor (GACS-FBBR) followed by a submerge membrane bioreactor (MBR) with the capacity of 2L per minute. The results indicated that the MBR-HS could effectively remove 90% DOC and 95% $NH_4$-N. $PO_4$-P removal efficiency was remained stable at about 70% throughout the experiment. Specific oxygen uptake rate (SOUR) of activated sludge increased from 0.72 to 2.21 mg $O_2$/gVSS.h for the first 10 days and then followed by a steady stage until the end of experiment. Sludge volume index (SVI) was always below 50 mL/g, demonstrated an excellent settling properties of sludge. The system also showed an achievement in terms of low trans-membrane pressure (TMP) development rate. The TMP increasing rate was only 0.65 kPa/ day, suggesting GACS-FBBR can be a promising pre-treatment for MBR.

***Keywords***: membrane bioreactor hybrid system, fluidized bed bioreactor, municipal wastewater, pilot scale

## 1. Introduction

Membrane bioreactor (MBR) has been increasingly consolidating its status as a state-of-the-art technology in wastewater treatment during the last few decades. Admittedly, this technology has several advantages over the conventional treatment systems, such as high treated water quality, less space requirement, and less sludge production. However, at the mean time MBR has an unavoidable obstacle which is difficult to overcome, namely membrane fouling (Guo et al., 2012). Membrane fouling reduces the membrane life, requires more energy for backwashing and makes the system less efficient. It is obvious that in practical application, assessing fouling mechanism with real wastewater and pilot scale system help further understanding of this topic as in several cases synthetic wastewater does not reflect genuine characteristics of the real one.

There has been recently enormous attention paid on examination of MBR performance in large scale. Most of recent studies indicated that treatment performance similar to that observed during bench-scale research may be obtained at a larger scale (Smith et al., 2012). Gao et al. (2009) developed a novel automatic vacuum MBR equipped with an on-line air–water–chemicals backwashing system for a purpose of the reclamation of domestic wastewater. The experimental setups were operated in pilot scale and experimental results indicated that membrane flux was able to resume as the fouled membrane modules being operated for 150 days. Compared to a new membrane module, the contaminated membrane fluxes were resumed to 94.7% after the first cleaning, to 82.7% after the second cleaning and to 70.0% after the third cleaning at a vacuum value of 20 kPa. To meet the standard of water reuse for car washing and land watering (PR China CJ25.1–89, COD concentration less than 30mg/L and ammonia nitrogen less than 10mg/L), the minimum HRT required by this system was 1 h for domestic wastewater reclamation. Lin et al. (2011) demonstrated that the submerged anaerobic MBR for municipal secondary wastewater treatment was technically feasible in terms of COD removal, sludge production and biogas yield. Membrane parameters, including flux, price and lifetime, played decisive roles in determining the total life cycle costs of the MBR system. The effectiveness of a full scale MBR in the removal of bacteriophages and bacterial fecal indicators from municipal wastewater was compared with that obtained by conventional activated sludge process (CASP) (De Luca et al., 2013). The MBR process was able to achieve respectively 2.7 and 1.7 Log10 higher reductions of somatic coliphages and F-RNA specific bacteriophages compared with CASP. In the meantime, the recent developments made in MBR have enhanced the performance of MBR, such as anaerobic MBRs using the Anammox process for nitrogen removal (Stuckey, 2012) and staged anaerobic fluidized MBR system for minimizing membrane fouling (Yoo et al. 2012).

Use of GAC in FBBR (GAC–FBBR) is an emerging technology for refractory organic pollutants removal, which was operated under anaerobic conditions (Xing et al., 2010). The GAC provides a temporary storage place, through adsorption, for occasions when the contaminant concentration is in excess of the bacterial capacity to transform. The contaminant then desorbs when concentrations decrease, maintaining the feed of the contaminant to the bacteria. GAC–FBBRs have also been used for treatment of coal gasification wastewaters and chlorinated solvents at the laboratory scale (Vidic et al., 1990). Initial studies of the GAC–FBBR were focused on the treatment of dinitrotoluene (DNT) in propellant wastewater. A bench scale study in a university laboratory, using synthetic wastewater, was undertaken to evaluate this technology for use in the field. The GAC–FBBR has also been evaluated in the laboratory environment for TNT degradation. A small scale system demonstrated that TNT could also be degraded (VanderLoop et al., 1999). The system was operated with ethanol as the electron donor and at constant influent concentrations. Biological GAC-FBBR has been shown to have the ability to remove the gasoline contamination from groundwater and provide both the efficiency of biological removal and the positive effluent protection capability of activated carbon adsorption.

Laboratory scale membrane bioreactor hybrid system (MBR-HS) was experimented in Environmental Engineering Laboratory, University of Technology, Sydney. The system included FBBR and sponge bioreactor followed by MBR (Nguyen et al., 2012). This system was successful in terms of organic and nutrient removal and reducing membrane fouling. By the end of 2010, a pilot scale MBR-HS was started and set up at the Water Reclamation Plant in Sydney Olympic Park. After the successful completion of the 2000 Olympic, Sydney Olympic Park Authority has undergone a significant amount of development work to support its conversion to a multipurpose facility with a number of businesses re-locating to the area. The collected domestic wastewater comes from sport arenas, office buildings, restaurants, hotels, and apartments in this area. The characteristics of the wastewater from the Water Reclamation Plant are quite different from synthetic wastewater used for laboratory scale experiments.

The objective of this study is to investigate the performance of MBR hybrid system on treating municipal wastewater in SOP under the assessment of the following parameter: (i) the removal efficiency of organics and nutrients; (ii) the relation of mixed liquor suspended solid (MLSS) and sludge volume index (SVI); (iii) specific oxygen uptake rate; and (iv) trans-membrane pressure (TMP) development.

## 2. Materials and methods

### *2.1. Municipal wastewaters*

The municipal wastewater used in this experiment was derived from Sydney Olympic Park. The wastewater had dissolved organic carbon (DOC) of 60-120 mg/L, COD of 271-385 mg/L, $BOD_5$ of 133-193mg/L and suspended solids of 116-182 mg/L. The wastewater also contained high ammonia-N ($NH_4$-N) and orthophosphate ($PO_4$-P) concentration of 21.4-51.2 mg/L and 3.7-6.4 mg/L, respectively. The pH of the wastewater was 7.44-7.52.

### *2.2. MBR-HS description*

Influent wastewater from Wastewater Reclamation Treatment Plant freely flowed into a 60L equalisation tank (Fig. 1). A fine screen of 2 mm was also placed on the way in order to completely retain the coarse solids found. Wastewater was then fed to the FBBR by a PTX 141 pump with the constant flow rate of 2 L/min. The FBBR was made of acrylic with an internal diameter of 19 cm, and 240 cm in height. About 22 L of GAC was filled in the FBBR. The coal based GAC (ACTICARB GS1300, Activated Carbon Technologies Pty Ltd., Australia) was used in this study. This coal based GAC has a surface area of >1100 BET$m^2$/g, an iodine number of >1100 mg/(g min) and maximum ash content of 10%. The height of GAC in the FBBR column was about 60 cm, and its height expanded approximately 20% with the upflow velocity of 37 cm/min. Wastewater from the FBBR was continually transferred into a sponge bioreactor. This reactor had dimension of 100 × 60 × 80 cm, with the working volume of 330 L. S28-30/90R polyurethane sponge cubs was added to the reactor with the fraction volume of 10%. Compressed air was used to supply oxygen and maintain the aerobic condition of the sponge bioreactor. Recirculation tank was placed after the sponge bioreactor in order to circulate wastewater back to the FBBR. 40 L/min (95%) of the wastewater was returned in this stage from the recirculation tank. To keep the recirculated wastewater under the anaerobic condition, nitrogen gas was unendingly provided into the bottom of the recirculation tank, through several air stones. Effluent water of the system was drawn from sponge bioreactor.The FBBR had hydraulic retention time (HRT) of 2.5h and organic loading rate (OLR) of 780-1100 gCOD/day. Membrane bioreactor was prepared for highly extended treatment for pre-treated water from the FBBR. The seed sludge for MBR was taken from the sequencing batch reactor at Water Reclamation Plant in Sydney Olympic Park and was acclimatized before starting the experiment. The reactor was made of acrylic with the working volume of 15 L. A flat sheet PVDF membrane with surface area of 0.2 $m^2$ and pore size of 0.14 µm was used in this experiment. The pre-treated water from the FBBR was collected and transferred into a 60 L feeding tank prior to the MBR. The experiment was conducted with activated sludge concentration of 5 g/L. The MBR was operated at flux of 10 L/$m^2$.h, backwash was applied one time per day (2 min duration) using filtrate with the backwash rate of 30 L/$m^2$.h. Pressure transducer with online data acquisition was used to monitor the TMP. A soaker hose air diffuser was used to maintain the air flow rate. The fouled membrane was physically cleaned after each stage prior to the next stage of the experiment.

**Fig. 1.** Experimental set up for the pilot scale MBR-HS experiment

*2.3. Analysis*

DOC of the influent and effluent was measured using the Analytikjena Multi N/C 3100.$NO_2$-N, $NO_3$-N, $NH_4$-N, and $PO_4$-P were measured by photometric method using Spectroquant ® Cell Test (NOVA 60, Merck).The measuring of mixed liquor suspended solid (MLSS)and mixed liquor volatile suspended solids (MLVSS) wascarried out according to Standard Methods (APHA, 1998). YSI 5300 Biological Oxygen Monitor was used to measure the SOUR. The oxygen consumption measurement can be achieved through the use of oxygen electrode with oxygen permeable Teflon membrane. Voltage generated from the reaction is proportional to the oxygen concentration of the sample and produces oxygen uptake during a period of 2-15 min.

**3. Results and discussion**

*3.1. pH, DO, and ORP*

Fig. 2 presents the pH, ORP, and DO of influent wastewater, sponge tank, and recirculation tank of the membrane bioreactor hybrid system. pH value of the system showed that the influent pH wastewater varied from 7.4 to 8.2 during the whole experiment. The pH of sponge tank and recirculation showed the value of 7.0-7.4 and 7.4-7.7, respectively. The results also indicated that the ORP of influent wastewater was

-30 to -220 mV and ORP of the sponge tank was positive, ranged between 50 to 200 mV. However, the recirculation tank ORP was almost below -50 mV, this was due to the supplying of nitrogen gas to maintain this reactor under the anaerobic condition. DO concentration of the influent wastewater was less than 0.5 mg/L, indicating the low oxygen environment of the input. By supplying air continuously into the sponge tank, the DO of this reactor was maintained between 2.5 to 3.0 mg/L. The DO concentration of the recirculation was also controlled under 0.5 mg/L by providing nitrogen gas all the time.

**Fig. 2.** pH, DO, ORP of influent, sponge tank, and recirculation tank of the pilot scale MBR-HS

*3.2. Organic and nutrient removal*

Fig. 3 presents the organic, $NH_4$-N and $PO_4$-P removal of the pilot scale MBR-HS. DOC removal efficiency was 80% at the beginning of the experiment and gradually increased to 90% after 7 days of operation. It was followed by a steady stage with the removal efficiency of 92% till the end of the experiment. The results also showed the successful achievement in terms of $NH_4$-N removal. It started with 85% removal at the first day and increased sharply to 95% just after 3 days of the experiment. The highest $NH_4$-N removal efficiency was observed at 95.8% in 5th day. It was gradually decreased to 90% after 20 days of operation and slumped to 82.5% at the end of the experiment. $PO_4$-P results showed 46% removal at the beginning of the experiment. It was increasing slowly, peaked 70% at day 17th. Thus, the GACS-FBBR could achieve high removal regarding DOC and $NH_4$-N. Zhang et al. (2012) investigated a submerged MBR with PVC hollow fiber membrane to treat municipal wastewater. The results showed that better removals of the main pollutants (90% CODCr and 92% $NH_4$-N).

Qiu at el. (2013) developed a lab-scale upflow anaerobic sludge blanket (UASB)-MBR process for berberine removal from synthetic wastewater. The performance of the UASB–MBR system on berberine, COD and $NH_4$-N removal was investigated at different berberine loadings. The overall removal rates of berberine, COD and $NH_4$-N consistently reached up to 99%, 98% and 98%, respectively.

**Fig. 3.** Organic and nutrient removal of the pilot scale MBR-HS

More specifically, the GAC-FBBR contributed 60-65% of DOC removal toward the total removal efficiency of the system, and the rest removed by MBR. Additionally, the GAC-FBBR alone achieved 55% of $NH_4$-N and 40% of $PO_4$-P removal before further removed by the MBR. The previous study also found an integrated fluidised bed bioreactor achieved 90% of DOC, 50-60% of T-N and T-P removal from primary treated sewage effluent (Xing et al., 2011).The relatively low phosphate removal in the system dues to the fact that municipal wastewater contains a large proportion of polyphosphates. Polyphosphates undergo hydrolysis in aqueous solutions and revert to the orthophosphate forms, which are available for biological metabolism without further breakdown; however, this hydrolysis is usually quite slow. Nitrification process has been examined in sponge bioreactor (SBR). The DO concentration of this reactor was always kept between 2.5-3 mg/L. In theory, the nitrification rate should not improve above 2 mg/L of DO. Influent $NH_4$-N of the SBR was $55.1 \pm 4.2$ mg/L and effluent was $24.1 \pm 3.7$ mg/L. The SBR yielded 89.3 gN/day of specific nitrification rate.

*3.3. Sludge SOUR*

The results of sludge SOUR indicated that microbial activity of activated sludge was increased during first 10 days, started from 0.72 mg $O_2$/gVSS.h at the first day and reached the maximum point of 2.21 mg $O_2$/gVSS.h at day 10th. It was followed by a slump to 1.92 mg $O_2$/gVSS.h and then remained stable until the end of the experiment. This result indicated that microbial activity was developing during first 10 days and followed by a steady stage till the day 25 of the experiment.

*3.4. MLSS and SVI*

Fig. 4 shows the MLSS and SVI of the activated sludge of the MBR-HS. The experiment was started with 5.2 g/L MLSS and 4.45 g/L MLVSS. Biomass concentration of the MBR was increasing as no sludge withdrawn took place. MLSS concentration increased with the rate of 64 mg/day, ended at 6.8 g/L after 25 days of operation. The development rate of MLVSS was a bit slower with the rate of 34 mg/L. At the end of the experiment, the MLVSS concentration was 5.0 g/L, increased 32.5 % as compared to the beginning of the experiment. SVI value of activated sludge was also proportional to the increasing of the biomass in the reactor. It was about 10 mL/g during the first 5 days of the experiment, and between 20 – 30 mg/L from day 7 to 15, and continually increased to 43 mL/g after 25 days of operation. In this present study, SVI value was always below 100 mL/g, indicating good settling properties of the sludge. High SVI is normally attributed to the growth of filamentous bacteria which negatively effects the characteristics of the activated sludge.

**Fig. 4.** MLSS and SVI of the activated sludge of the MBR-HS

*3.5. TMP development*

TMP development of the MBR-HS was measured daily in this experiment. The increasing of TMP in this experiment can be divided into two parts, the first 17 days and from day 17th to the end of the operation. TMP was 3.25 kPa at the first day of the experiment and was gradually increasing to 14.35 kPa at day 17$^{th}$. The TMP development rate at this stage was 0.65 kPa/day. Nevertheless, the TMP increased dramatically in the second stage with the development rate of 4.04 kPa/day. It was 48 kPa at the end of the experiment. This TMP development rate was relatively low compared to previous study of Shan et al. (2012), achieved of about 10 kPa/day at HRT of 1hr. This result indicated the membrane was fouled severely after 17 days of operation. This could be explained by the less frequency of backwash for the membrane (only once per day for 2 min).

**4. Conclusions**

The pilot-scale FBBR-MBR hybrid system could remove more than 95% of organic carbon and $NH_4$-N, and more than 70% of $PO_4$-P when treating municipal wastewater. Microbial activity of the sludge of the FBBR-MBR hybrid system gradually increased during the first 10 days of the experiment, reached the peak of 2.21 mg $O_2$/gVSS.h, and followed by a steady stage. SVI was always below 100 mL/g, indicating the good settling property of activated sludge. The hybrid system was successful in mitigating the membrane fouling as the TMP development of only 0.65 kPa/day.

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## FIGURE CAPTIONS

**Fig. 1.** Experimental set up for the pilot scale MBR-HS experiment

**Fig. 2.** pH, DO, ORP of influent, sponge tank, and recirculation tank of the pilot scale MBR-HS

**Fig. 3.** Organic and nutrient removal of the pilot scale MBR-HS

**Fig. 4.** MLSS and SVI of the activated sludge of the MBR-HS

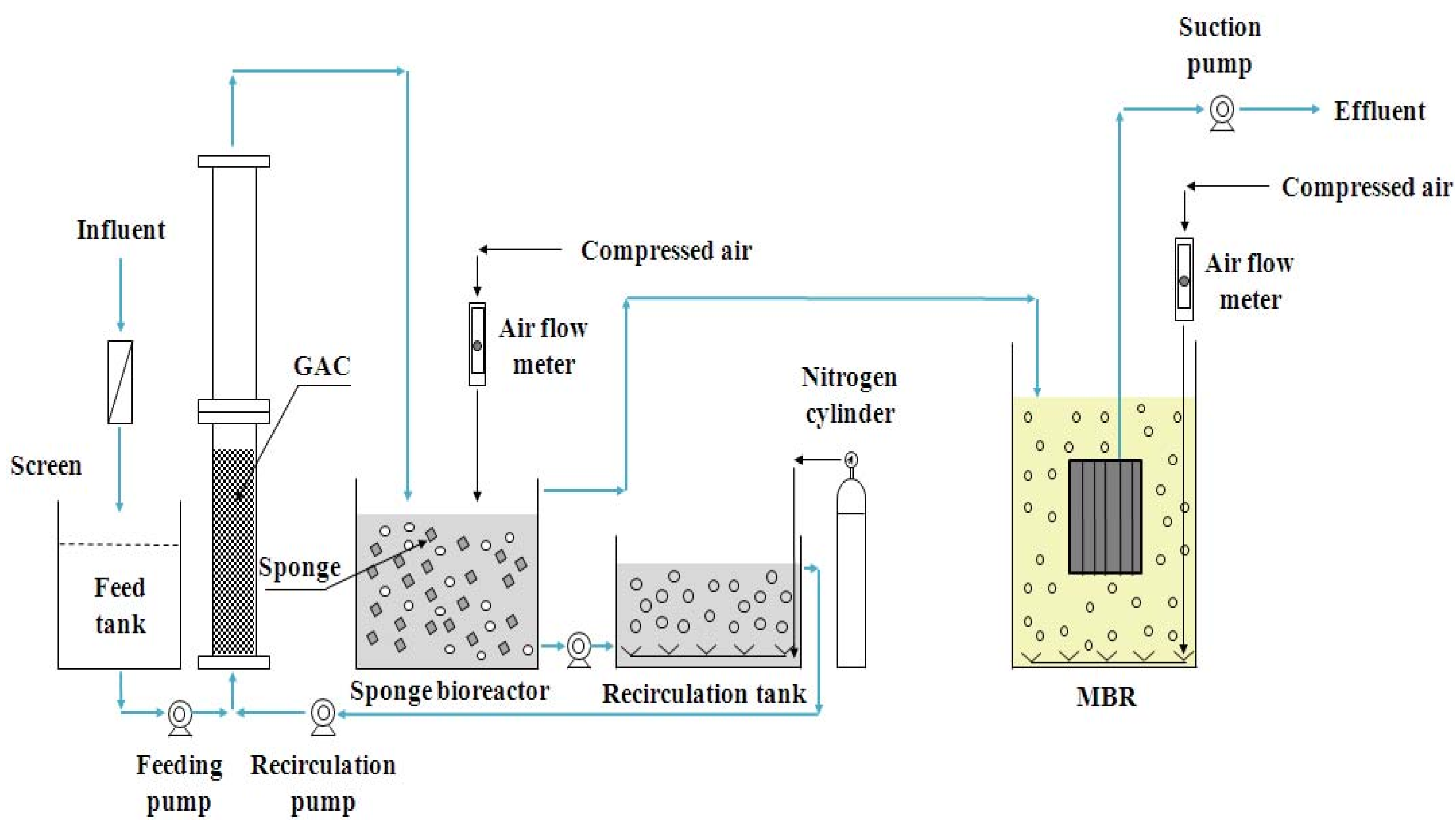
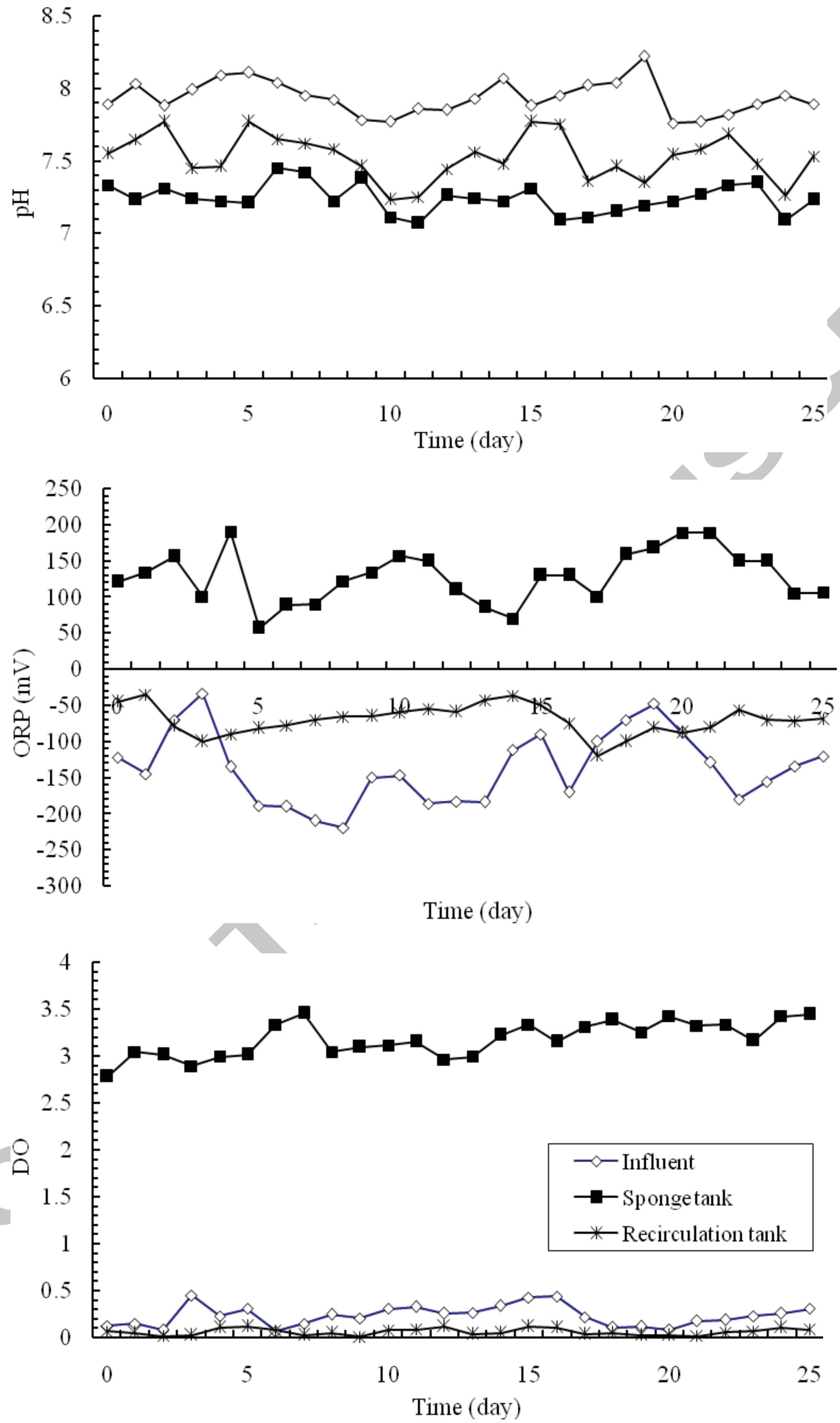

Influent
Screen
Feed
tank
GAC
Sponge
Feeding
pump
Recirculation
pump
Compressed air
Air flow
meter
Sponge bioreactor
Recirculation tank
Nitrogen
cylinder
Suction
pump
Effluent
Compressed air
Air flow
meter
MBR

Figure 1



8.5
8
7.5
7
6.5
6
pH
0
5
10
15
20
25
Time (day)
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
ORP (mV)
Time (day)
4
3.5
3
2.5
2
1.5
1
0.5
0
DO
Influent
Sponge tank
Recirculation tank
Time (day)


**Figure 2**

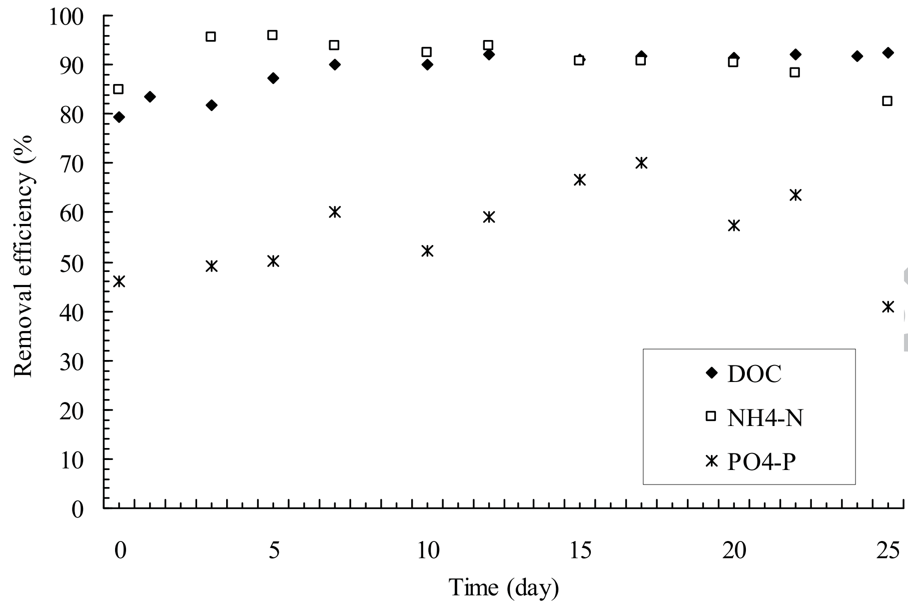

100
90
80
70
60
50
40
30
20
10
0
Removal efficiency (%
0
5
10
15
20
25
Time (day)
DOC
NH4-N
PO4-P

**Figure 3**

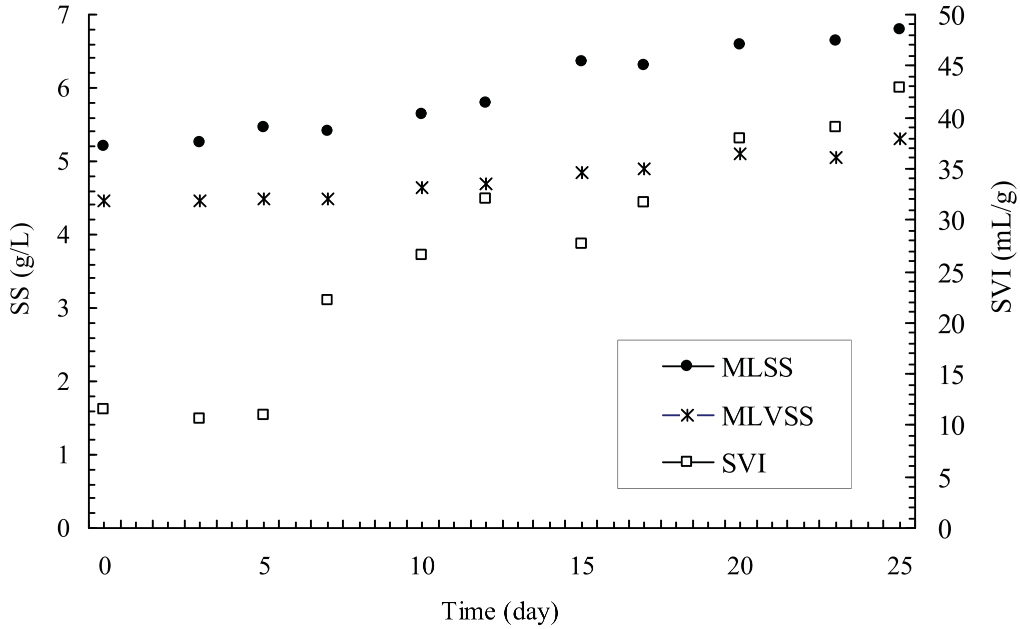

7
6
5
4
3
2
1
0
SS (g/L)
50
45
40
35
30
25
20
15
10
5
0
SVI (mL/g)
0
5
10
15
20
25
Time (day)
MLSS
MLVSS
SVI

**Figure 4**

## HIGHLIGHTS

- The pilot scale GACS-FBBR-MBR was successful in treating municipal wastewater.
- GACS-FBBR is a promising pre-treatment method for membrane bioreactor.
- SVI was below 100 mL/g, indicating the good settling property of activated sludge.
- The hybrid system was successful in mitigating membrane fouling.