Submerged Membrane-Adsorption System: An Energy Efficient Process for Water Reuse

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EXECUTIVE SUMMARY

Membrane separation process is being emerged as an innovative wastewater treatment technology. However, its use at present is limited due to its high cost of installation and its long-term operational difficulty. Membrane fouling is a major obstacle to the successful operation of the membrane separation process. The membrane processes such as reverse osmosis and nano-filtration can remove most of the pollutants, including dissolved organics, but their operational costs are high because of high-energy requirements and membrane fouling. Micro or ultra-filtration is a cost-effective option, but they cannot remove dissolved organic matter due to their relatively larger pore sizes.

The membrane fouling can be reduced by operating the membrane process under critical velocity and/or by combining the membrane processes with physico-chemical and/or biological processes. In this study, a submerged hollow-fibre membrane with powdered activated carbon (PAC) adsorption (adsorption-membrane hybrid system) was investigated for the removal of organics from biologically treated sewage effluent from a sewage treatment plant and a low strength synthetic wastewater. The main aim of adding PAC to the system was to reduce the direct organic loading to the membrane surface. In this hybrid system, the organics are adsorbed onto the PAC, and the organic laden PAC is eventually separated by the membrane. In long run, after the growth of microorganisms on PAC surface, the organic would be biodegraded by the microorganisms and thus the PAC can be used for long time. The membrane is also free from fouling (or very little fouling) and thus can be used for long time without cleaning. The membrane was submerged in a tank containing wastewater. A known dose of PAC was added to the tank. An air diffuser was used to keep the PAC in suspension and to provide dissolved oxygen for biological activity. The influent and effluent flows to and from the tank were maintained using pumps.

The level of wastewater in the tank was maintained with the help of a level sensor. The membrane fouling was observed in a transmembrane pressure gauge.

The hybrid system was tested for its long-term use in wastewater treatment. The use of PAC in the membrane system was found very effective, not only in removing refractory organics but also in reducing membrane clogging. The organic removal efficiency of the system was consistent for 47 days for the biologically treated sewage effluent. There was very little pressure drop, which meant the membrane fouling was negligible. This system led to an initial 85% organic removal with the low strength synthetic wastewater. However, the efficiency decreased to 55 % after 20 days operation, then after the efficiency remained consistent upto 30 days of operation. After 30 days of continuous operation, the membrane experienced significant blocking and the desired filtration flux of 0.288 m^3/m^2d could not be maintained. When the PAC dose was increased to 5 g/L and membrane backwashing provided (at 0.87 m^3/m^2d for 2 mins; once per day), the organic removal efficiency remained consistent at 80% even after 40 days of operation, and there was no pressure increase observed. Thus, with the higher PAC dose and/or simple backwash mechanism, the system could achieve higher organic removal efficiency, and longer periods of operation. This submerged membrane-adsorption hybrid system has many advantages. The PAC can be used for a long period. As adsorbed organics undergo biodegradation, more adsorption sites are created on the PAC surface. The submerged membranes do not become clogged as almost all organics are removed by PAC and the role of membrane is only to retain the PAC and other suspended solids. The energy requirement is very low (as low as 0.2 kwh/m^3) and no sludge problem. These experimental results showed that the membrane separation process when used in conjunction with adsorption could be a viable long-term solution to the problems currently associated with the application of membrane.

Key Words. Adsorption, biologically treated sewage effluent, hollow fibre membrane, powdered activated carbon (PAC), total organic carbon (TOC)

INTRODUCTION

Conventional sewage treatment includes primary treatment to remove the majority of suspended solids, secondary biological treatment to remove the biodegradable dissolved organics and nitrogen, and tertiary treatment to remove most of the remaining organics, solids, and pathogenic micro-organisms. In water reuse applications, tertiary wastewater treatment system traditionally undergoes the physico-chemical processes such as flocculation, sedimentation, and filtration. With technological advances and the ever-increasing stringency of water quality criteria, membrane processes are becoming a more attractive solution to the challenge of water reuse. Although membrane processes such as reverse osmosis and nano-filtration could in theory remove all pollutants, including dissolved organics, their operational costs are high because of high-energy requirements and membrane fouling. Micro or ultra-filtration is a cost-effective option, but they cannot remove dissolved organic matter due to their relatively larger pore sizes. Addition of powdered activated carbon (PAC) to micro/ultra filtration systems (known as an adsorption-membrane filtration hybrid system) is emerging as a highly promising water and wastewater treatment technology (Vigneswaran et al., 1991; Seo et al., 1997; Snoeyink et al., 2000; Kim et al., 2001; and Matsui et al., 2001a, 2001b). In this process, the pollutants (particularly the dissolved organics) are first adsorbed onto PAC, so greatly reducing the direct loading of dissolved organic pollutants onto the membrane. The addition of adsorbent (e.g. PAC) facilitates the removal of refractory organics. Kim et al. (2001) used the membrane hybrid system to remove organics and coliphase Qβ strain from synthetic wastewater (TOC = 10 mg/L). They found that the organic removal efficiency of the system was consistently more than 95% with 40 g/L of PAC dose for 40 days.

The initial decrease in the permeate flux in microfiltration is mainly due to rapid, irreversible adsorption of organic substances onto the membrane surface (Ben Aim et al., 1993). Therefore, the pre-adsorption of organics prior to passage of the wastewater solution through the membrane promises to be very effective in reducing membrane fouling.

The adsorption-membrane hybrid system can be operated in either external loop or in submerged mode. As shown in Figure 1, the operation in external loop (crossflow microfiltration) requires higher-energy demand as there is direct contact of PAC on the membrane surface. To reduce the energy requirement, membrane clogging and to simplify the process, the submerged membrane (dead-end operational mode) seems to be as a better solution (Visvanathan et al, 2000). In the submerged hybrid system, the entire treatment activity (namely adsorption/biodegradation, solid-liquid separation, and sludge accumulation and withdrawal) can be carried out in a single unit. The PAC is kept in suspension and thus there is less chance of membrane fouling due to the deposition of PAC on the membrane surface.

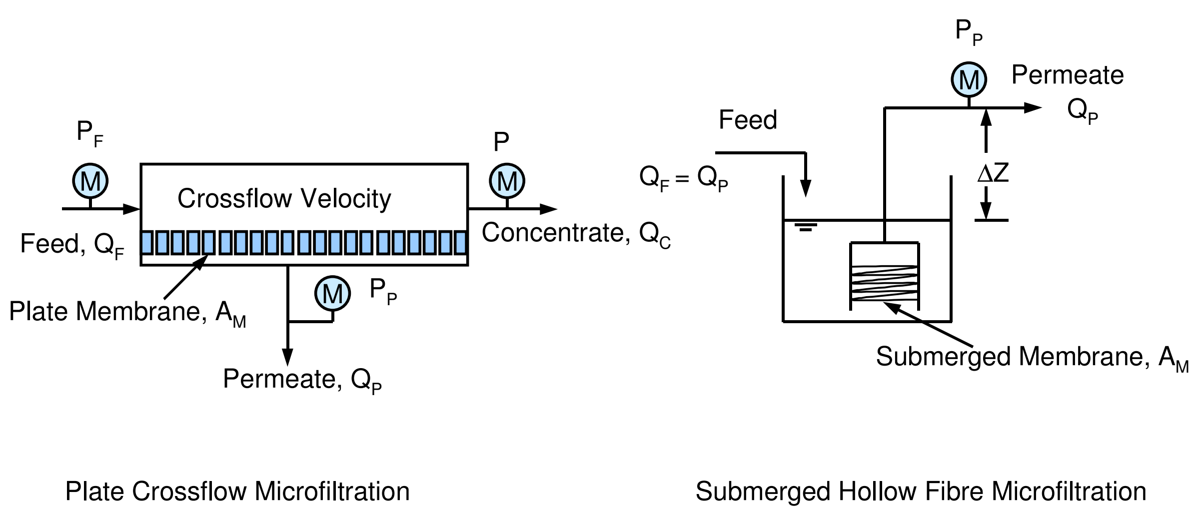


Figure 1 Illustration of flow patterns and transmembrane pressures in dead-end and crossflow microfiltration

EXPERIMENTAL INVESTIGATION

The schematic diagram of the submerged hollow fibre microfiltration system is shown in Figure 2. Wastewater (biologically treated sewage and synthetic wastewater) was pumped into the reactor using a feed pump controlling the influent and effluent flow rate. A predetermined amount of PAC was added into the tank to adsorb the dissolved organic substances, which was subsequently separated by the membrane filtration imposed by the suction pump. The inflow and outflow of the wastewater solution were kept equal to maintain a constant volume of wastewater in the reactor. A pressure gauge was used to measure the transmembrane pressure of the hybrid system. An air diffuser was used to maintain the PAC in suspension. This also provided the dissolved oxygen necessary to maintain the microbial community in the reactor when the system is used for long-term. However, this study was limited to short-term adsorption-membrane filtration only.

The low strength synthetic wastewater was prepared using 3 organic and 7 inorganic compounds. The composition of the synthetic wastewater is shown in Table 1. This represents the well-treated secondary effluent from a biological wastewater treatment plant (TOC = 3.5 mg/L and COD = 30 mg/L) (Matsui, et al., 1998). The TOC contribution of glucose, peptone and yeast extract with inorganics are 79%, 11% and 10% respectively.

Tables 2 and 3 present the properties of the PAC and the hollow fibre membrane used in this study.

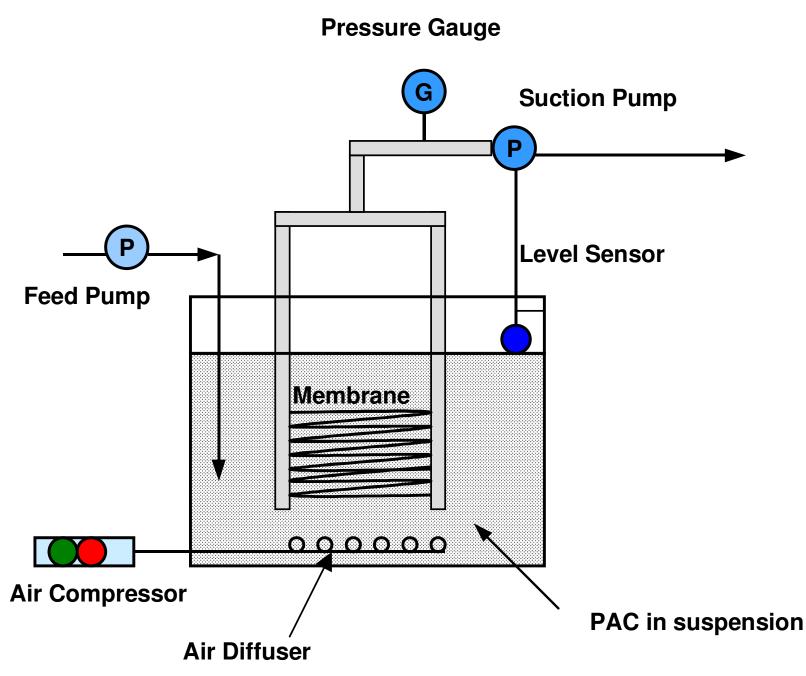


Figure 2 Schematic diagram of the submerged membrane hybrid system

Table 1 Constituents of the Synthetic Wastewater

Compounds	Weight (mg/L)	Compounds	Weight (mg/L)
$MnSO_4$	0.125	KH_2PO_4	1.250
$CaCl_2$	0.925	$NH_2.NH_2.H_2SO_4$	3.500
$NaHCO_3$	0.875	Glucose	16.500
NaCl	2.500	Yeast Extract	1.750
$MgSO_4.7H_2O$	3.750	Peptone	1.750

Table 2 Physical properties of the PAC *

Specification	Estimated Value
Iodine number, mg/g.min	900
Maximum Ash content	6 % max
Maximum Moisture content	5 % max
Bulk density, kg/m^3	290 – 390
BET surface area, m^2/g	900
Nominal size, m	80 % min finer than 75 µm
Average pore diameter, Å	25.3

* Supplier: James Cumming and Sons P/L, Sydney, Australia

Table 3 Physical and chemical properties of the membrane#

Properties	Hollow fibre membrane
Total Surface area (m^2) (320 fibres with 12 cm length)	0.05
Pore size (µm)	0.1
Material	Polyethylene
Inner diameter (mm)	0.27
Outer diameter (mm)	0.41

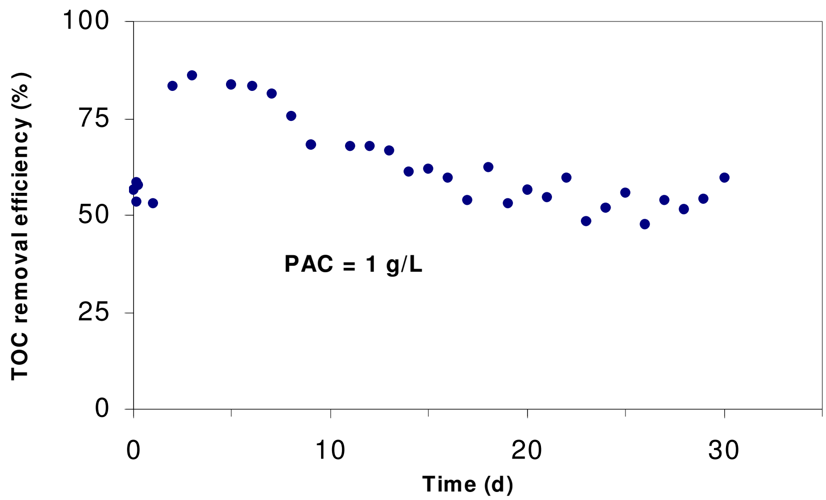
supplier: Mitshubishi, Tokyo, Japan

RESULTS AND DISCUSSION

The hybrid system was tested first with the synthetic wastewater. It was operated continuously for a month. Initially, the TOC removal efficiency of the hybrid system was around 85%. The system maintained the organic removal efficiency of 55% even after 30 days of continuous run, which is a quite favourable result for its application in practice (Figure 3). However, after 30 days of operation, the filtration flux could not be maintained consistent at 0.288 m^3/m^{2}d. When the system was backwashed with the effluent at the rate of 0.87 m^3/m^{2}d (3 times filtration flux), the organic removal efficiency of the system was maintained above 80% for 40 days (Figure 4). After the success with the synthetic wastewater, the hybrid system was further tested using biologically treated sewage from a sewage treatment plant, Sydney. It was used continuously for 47 days. The TOC removal efficiency of the system was around 65% for 27 days for the PAC dose of 1 g/L (Figure 5).

The TOC removal efficiency of the system increased successively for 47 days when additional doses of PAC were fed into the reactor (step feed). It shows that the adsorption-membrane hybrid system has potential of its use in practice. The efficiency of the system can be controlled by changing the PAC dose to the system. During the initial stages of the operation, organic removal is mainly due to adsorption onto PAC, but after a few days of operation, when the adsorption capacity of the PAC is reached, the removal of organics appears to be due to biological degradation caused by the microbial communities, which grow in the suspension of the reactor, and on the PAC (Figures 3 and 5). There is also biodegradation of organics adsorbed onto the PAC and a subsequent adsorption on the renewed PAC.

Figure 3 Long-term performance of the non-backwashed submerged membrane hybrid system with synthetic wastewater (Average influent TOC of the synthetic wastewater = 3.0 mg/L, filtration flux = 0.288 m^3/m^2d)



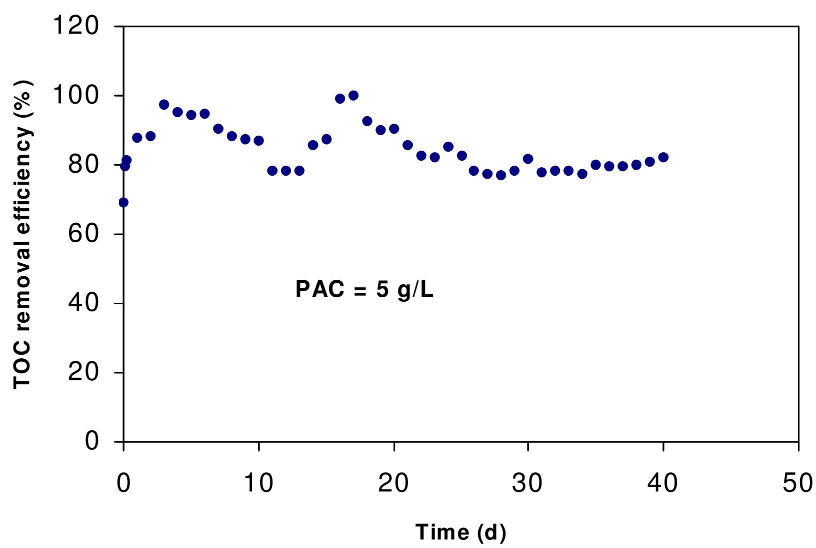


Figure 4 Long-term performance of the daily-backwashed submerged membrane hybrid system with synthetic wastewater (Average influent TOC of the synthetic wastewater = 2.0 mg/L, filtration flux = 0.288 m^3/m^2d, daily backwashing with the effluent at filtration rate of 0.87 m^3/m^2d for 2 minutes)

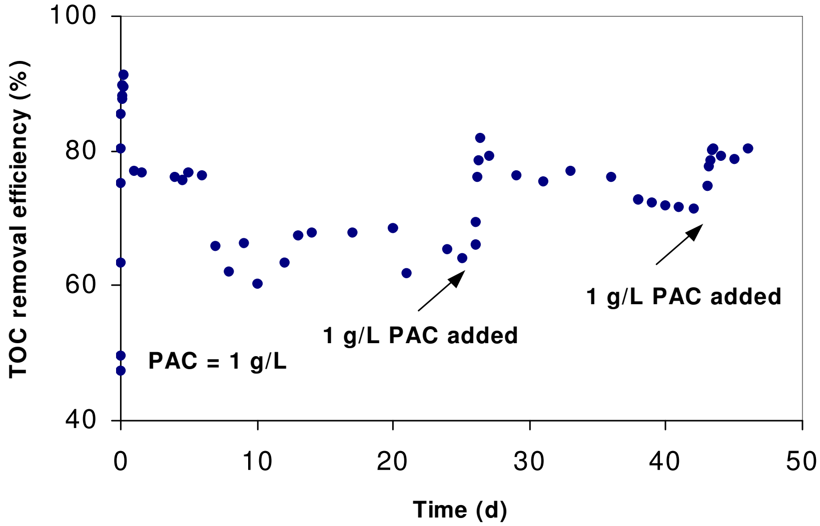


Figure 5 Long-term performance of the non-backwashed submerged membrane hybrid system with biologically treated sewage (Average influent TOC of the biologically treated sewage = 3.0 mg/L, filtration flux rate = 0.288 m^3/m^2d)

CONCLUSIONS

The submerged PAC-Membrane hybrid system was found effective in removing dissolved organic substances both from the biologically treated secondary sewage and the synthetic wastewater. The system has significant potential for long-term application in the treatment and re-use of wastewater. The efficiency of the system can be maintained easily by controlling the PAC dose to the system. The pre-adsorption of organics onto PAC helps to reduce the membrane fouling and maintain a consistent permeate flux. The adsorbed organics on the PAC is biodegraded with time, and hence it creates sites for further adsorption of organics on the PAC. Thus, this process facilitates long-term use of PAC in the system. With a selection of an appropriate PAC dose and operational parameters such as filtration flux and backwashing frequency, the adsorption-membrane hybrid system can be effectively implemented in practice.

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