특별강연 4

분리막을 이용한 하수처리 MBR 공정

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MBR technology for wastewater treatment

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1. Introduction

MBR (Membrane Bio-Reactor) process for wastewater treatment, which replaces the two stages of the conventional activated sludge process (clarification and settlement) with a single, integrated bio-treatment, has been widely practiced. There are 500 commercial MBRs in operation worldwide, with many more proposed or currently under construction [1]. Advantages offered by MBR over conventional treatment technologies are well known and have been reviewed elsewhere [2]. Nevertheless, the widespread application of the MBR processes is constrained by the high capital, maintenance and operating costs. In recent reviews covering membrane applications to bioreactors it has been shown that as with other membrane separation processes membrane fouling is the most serious problem affecting this system [3, 4] Fouling leads to permeate flux decline, making frequent membrane replacement and cleaning necessary, which then increases maintenance and operating cost. Fouling problems can be greatly ameliorated by operating at low flux, but this then demands a greater membrane area.

Therefore, low cost MBR system is strongly required at this moment.

This study consists of two parts; the first is an application of low cost membrane to submerged MBR. The feasibility of a submerged MBR fitted with NWPP (Non-Woven Poly-Propylene) membranes has been studied. The second part is about an enhancement of flux using air sparging technique.

2. Experimental

Membrane bioreactor was constructed of perspex having a working volume of $0.035m^3$. Two plate-and-frame membrane modules were immersed in each of the bioreactors, each having a membrane surface area of $0.24m^2$. The feed pressure to the bioreactor was set at 6kPa by the constant head device. Compressed air was supplied through aerator stones via a compressor. The NWPP membranes used were of 1.5, 3 and 5 m nominal pore size, whereas the commercial PS membrane, currently used in a full-scale submerged MBR plant for municipal wastewater treatment, had a quoted pore size of 0.3μm. The feed supplied to the system was screened and settled primary influent and was supplied at constant pressure.

The other membrane bioreactor ($0.6m^3$) equipped with an air sparging device was operated. Details of the membrane bioreactor should be refereed to the reference [5]. Two air-injection configurations for the submerged MBR were studied: intermittent air-jetting into a module sealed at one end (air-jet mode), and conventional air lift allowing circulation of the mixed liquor in the bioreactor (air-lift mode). The applicability of each was evaluated with a series of lab-scale experiments using a domestic wastewater. The transmembrane pressure (TMP) was applied by using a head of water, and was kept at around 3.4 to 7.1 kPa. The membranes used were polyethersulfone with a nominal pore size of 0.2 m. Screened and settled primary effluent from the Cranfield University (UK) sewage treatment works were supplied to the bioreactor.

3. Results and Discussion

3.1 MBR with low cost membrane

To give biomass time becoming accustomed to different hydraulic condition the bioreactors were seeded with activated sludge on day 0 and left to acclimatise for 24 hours. Permeate drains were then opened and the feed flow initialised. All membranes showed a very rapid flux decline in the first 1.5 hours (Fig. 1a). After 20 days, the flux for the NWPP membranes declined to between 2 and 8 $lm^{-2}h^{-1}$, whereas that of PS membrane was ~10 $lm^{-2}h^{-1}$ (Fig 1b). It appears that fouling of the membrane is most critical at the start of filtration, and the build-up of the fouling layer in the first few hours of start-up is thus critical in determining operability.

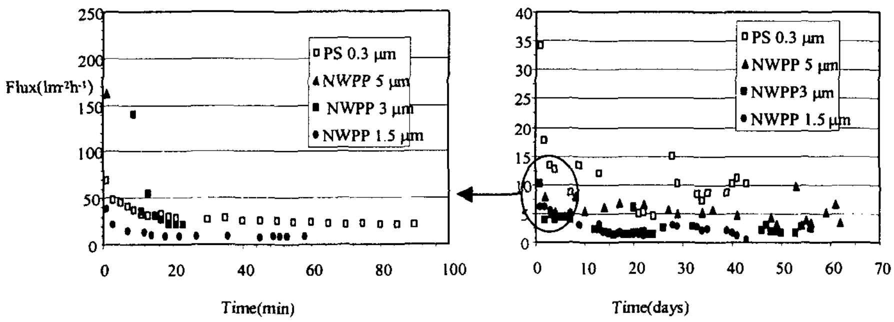

Fig. 1 Permeate flux decline from the PS and NWPP membranes; (a) initial flux decline, (b) overall experimental period

As with other MBR studies, BOD_5 removal is high (>91%) for all three membranes. Permeate BOD_5 ranged from 3 to 6 mg/l. The substantial variation in influent BOD_5 load, had little adverse effect on organic removal rates. The average permeate turbidity was very low at <1 NTU, representing 99% removal. Ammonia removalsfor all membranes were higher than 60% at all times. These data indicate the NWPP-based to be efficient in treating wastewater.

Table 1 shows the log reduction of total coliforms (TCs) for all membranes. Effluent from the PS membrane showed a mean 7-log reduction in TCs. However, NWPP membranes attained only a 2~4-log reduction, thereby failing to meet the EU Bathing Water Directive (1976) in this regard.

Table 1. Performances of the bioreactors equipped with different membrane materials

Characteristics	BOD_5 Removal (%)	Turbidity (NTU)	Ammonia Reduction (%)	Coliform Reduction
NWPP membrane (1.5 μm)	95 ~ 98	0.2 ~ 0.7	63 ~ 99	3 ~ 5 -log
NWPP membrane (3 μm)	97 ~ 99	0.2 ~ 0.7	66 ~ 98	3 ~ 5 -log
PS membrane	97 ~ 99	0.1 ~ 0.5	93 ~ 99	~ 7 -log

It is apparent that the NWPP membrane pore size had little effect on TCs reduction, probably due to the formation of a dynamic layer. As most of the filtration resistance in an MBR arise from the cake layer [6, 7], it is reasonable to expect this layer, rather than the NWPP membranes substrate, to be responsible for the measured coliform rejection.

3.2 MBR with air sparging

Operation of the air-lift module over period of 37 days was conducted with and without backwashing and air sparging (Fig 2). For concurrent backwashing and air sparging ("a+b" in Fig 2), the flux exhibited a steady state value (30-32 lm-2h-1). During the backwashing-only mode ("b" in Fig 2) the flux decreased to ~22 $lm^{-2}h^{-1}$, indicating a 30% decrease in flux due to cessation of air injection. This compared with a stable flux of 17~20 $lm^{-2}h^{-1}$ for air sparging-only mode ("a" in Fig 2), indicating that backwashing had a slightly greater influence on flux than air sparging. However, considering that the backwashing is carried out so frequently (2 min backwashing per 30 min operation), the air sparging effect on flux is relatively great.

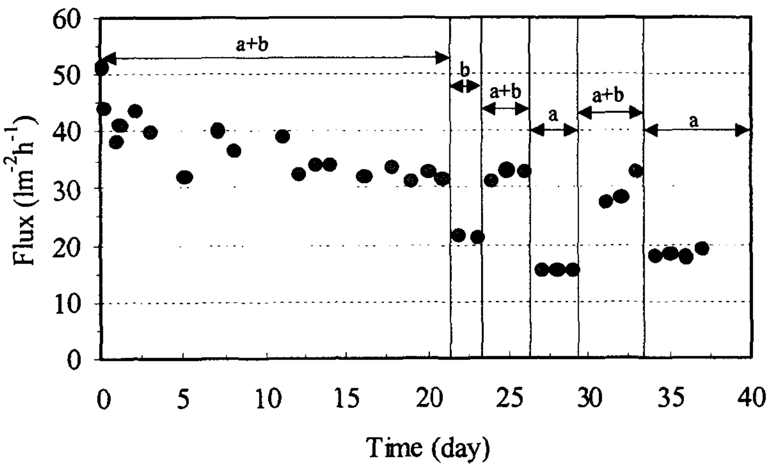

Fig. 2 Effect of backwashing and air-injection on flux performance of the air-lift module; (a)air only, (b) backwashing only, (a+b) air and backwasing together

As with other MBR studies, COD removal is high (>93%) for all period of operation, with the permeate COD ranging from 4 to 20 mg l-1 for a feedwater COD of 200 to 3000 mg l-1, of which around 22% was soluble. As with other reported MBR studies, the substantial variation in influent COD load had little adverse effect on organic removal rates.

The air-jet module was operated with and without backwashing, and normalized flux data for this module reveals backwashing to produce a stabilized flux of around 70% of the initial flux after around 150 hours. This compares with a gradual decline to about 10% of the original flux after 300 hours for non-backwashed operation. On investigating the membrane module it was apparent that, without backwashing, solids gradually accumulated in the lumens inside the membrane module leading to terminal clogging. Clearly, in this case the air-jet was insufficient to prevent accumulation of solids. Doubling both the air pressure (and thus the flow rate) had no significant effect on the rate of solids accumulation. The clogging phenomenon seems to be inherent in the air-jet design (dead end filtration), whereas no such clogging takes place for the air-lift process.

Comparison of flux data for the two operational modes, under non-backwashing conditions, reveals the relative flux (J/J_o) for the air-jet module to be greater than that of the air-lift module for the first 100 hr of operation. Whilst the flux for air-lift mode exhibited a steady state value, that of the air-jet mode decreased continuously due to lumen clogging, indicating that clogging inside air-jet module had been developing. After 240 hrs of operation the flux for the air-jet module was less than half that of the air-lift module.

It is evident that the air-jet sparging can produce up to 20% higher fluxes than the classical air-lift mode provided clogging is absent. It is known that the pressure inside an air-jet membrane channel fluctuates with response to the air-jet pulsation. The pressure variations inside the channel caused by air pulsation appear to promote permeate flux; a periodic decrease in pressure creates back-transport of permeate which would then be expected to help to dislodge the cake layer, especially when combined with the turbulent two-phase flow regime.

4. Conclusions

MBR based on low-cost non woven polypropylene (NWPP) microfiltration (MF) membranes have shown to perform comparably with an identically-configured MBR employing a commercial polysulphone (PS) membrane in terms of organics removal, nitrification and clarification. The reduction in throughput experienced with the NWPP membrane is attributable to internal fouling. Notwithstanding this, a stabilized flux of more than half that of the commercial membrane was achieved using a NWPP membrane of nominally 3μm pore size. Based on membrane module production costs of 10 m^{-2}, the MBR NWPP membrane capital cost per unit volume of treated effluent would be expected to be about half that of a conventional PS membrane module employed for this duty using the same flat plate module configuration.

The reduced membrane cost is offset to some extent by the limited disinfecting capacity of the low-cost membranes. All the NWPP membranes tested were subject to passage of microorganisms, giving log rejections of between 1 and 4 compared with 4-7 for the commercial PS membrane. On this evidence, low-cost NWPP membranes may be used in MBRs for bulk sewage and industrial effluent treatment, but would be less appropriate for wastewater reuse or any duty where disinfection is a pre-requisite.

Two kinds of air sparging technology, the air-lift and the air-jet, have been applied to enhance flux in a submerged MBR. For the air-lift module, permeate flux was found to increase by 43% when coarse bubble aeration was employed. No further increase in flux was observed as the gas flow was increased by up to a factor of five. The air-jet module suffered from clogging due to the gradual accumulation of biosolids inside the lumen over the operational period. However, provided clogging could be prevented the flux was greater than attained in the air-lift module under otherwise comparable operating conditions. Further work is needed to optimize start up and operating conditions to ameliorate clogging problems encountered with air-jet module.

5. References

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