OPTIMISING TREATMENT TECHNOLOGY FOR WATER RECLAMATION – A WAY TO PROTECT OUR RIVERS

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Abstract

Water reclamation can have important benefits for river health. This study involves the optimization of the micro filtration process for secondary effluent reuse. The micro filtration unit was operated in constant flux mode and the system was periodically backwashed with air to remove the filter cake layer. To achieve efficient cleaning the backwashing was actuated when the transmembrane pressure (TMP) reached a set value. Optimal operating conditions depend on the criteria adopted. An analysis based on energy and capital cost indicates that if energy saving is the objective the unit needs to be operated at low imposed flux. Similar conclusion can be drawn if environmental impact is the major concern with a Life Cycle Assessment (LCA) analysis leading to optimal fluxes of 10 to 20 L/m2.h. However if the criteria is based on conventional economics, which combines capital and energy costs, optimal operation would be at about 60 to 70 L/m^2.h for TMP$_{max}$ of 20 kPa or above 80 L/m^2.h for TMP$_{max}$ of 50 kPa. Thus the operating strategy depends on whether the aim is to operate for energy saving and low environmental impact or total cost saving. From the viewpoint of sustainability, which favours healthy rivers, the low flux option is desirable and this will require a radically different approach to the application of membrane technology in water reclamation.

Keywords

Sustainability, Energy Demand, Life Cycle Assessment, Microfiltration, Secondary Effluent

INTRODUCTION

Growing population coupled with the rise in standard of living around the world has led to higher demand for water for domestic, industrial and agricultural purposes. This has put a severe stress on river health. Firstly more water is impounded in the dams to meet the increasing demand thus less water is available for environmental flows in the river system. Secondly more and more wastewater is discharged into rivers with adverse affects on river ecosystems. Although in most cases wastewater is treated before discharge, the presence of nutrients can lead to algal blooms and eutrophication. In such scenario water reclamation for reuse can reduce the demand for fresh water and discharge of wastewater, with beneficial effects on our rivers.

There are many advanced treatment technologies available for water reclamation. Among them membrane technology is increasingly favored due to its ability to act as an absolute barrier to most pollutants including pathogens. In many situations microfiltration (MF) alone is used as an additional purification step prior to reuse of secondary effluent as non-potable water. Some notable examples in Australia are the water reuse process at the Sydney Olympic village and the Rouse Hill reuse scheme (Cooney, 2001; Cooper, 2003). On the other hand some industrial reuse applications, such as boiler feed water, need desalting by reverse osmosis (RO). Even in this case pretreatment of the secondary effluent is needed before RO. Here too MF is widely used as the pretreatment step (Masson and Deans, 1996; Barr, 2002). Previous studies indicate that microfiltration is a cost-effective option compared to conventional pretreatment methods and also contributes to improved productivity of the RO (Adham *et al*., 1997; Conklin *et al*., 1995). According to Leslie *et al*. (1998), a combined membrane process using either MF or UF hollow fiber membranes followed by reverse osmosis (RO) spiral wound membranes is recognized as the low cost alternative for municipal wastewater reuse plants. However water reuse is not widely practiced. One of the major impediments to the widespread application of water reuse is its perceived lack of cost competitiveness. Thus any improvement to the operation of the microfiltration step will have a positive impact on the cost of reclaimed water and consequently its widespread application. However, from the view point of sustainability the reclamation process should have a minimal environmental impact. It is unlikely that the criteria for conventional economics and those for environmental impact will lead to similar optima. Our analysis aims to explore this difference.

The membrane filtration process tends to be an energy intensive process due to the build up of fouling materials on the membrane surface, which leads to increased resistance for filtration. Studies by Defrance and Jaffrin (1999) indicate that controlled permeate flow would reduce the instantaneous fouling of membranes at the beginning of the filtration cycle. Crossflow and/or back washing also limit fouling, and for low energy operation dead-end flow with periodic back washing with air or permeate is preferred for dilute feeds such as secondary effluent. High-pressure air backwashing is more effective than liquid backwash particularly for secondary effluent filtration, but it is an energy intensive process. Therefore, increasing the backwash interval should lead to energy and cost savings as well improved productivity. The current approach of timed periodic back washing may not be optimal when feed water quality continues to vary. The back washing could be too frequent (energy expensive) when there is less foulant or insufficient when there is a rapid foulant build up (fouling potential leading to energy demand). To avoid this, backwash initiation based on Tran membrane pressure (TMP) could be employed and optimised (Parameshwaran *et. al*., 2001).

In this study a microfiltration unit was operated in the dead end, constant flux, mode and a high-pressure air backwashing was initiated at set TMP instead of set time interval. We have examined the effect of the magnitudes of the imposed flux and maximum TMP allowed; on energy demand, production cost and fouling potential. From this analysis we have identified conditions that minimise conventional economic cost. In addition to the conventional economics the MF reclamation process has been assessed in terms of total environmental impact by Life Cycle Analysis (LCA) to identify the impacts on the environment. Particular attention has been paid to identify impacts to fresh water ecology and eutrophication for typical Sydney region conditions.

METHODOLOGY

Data for this study were collected on a microfiltration pilot plant filtering secondary effluent from brewery wastewater. In this process wastewater from the fermentation stage is treated in a pilot Up-flow Anaerobic Sludge Blanket (UASB) reactor followed by a Sequencing Batch Reactor (SBR) to obtain the MF feed. The pilot MF unit provided by US Filter Memcor had a hollow fibre membrane module with a filtration area of $1m^2$. The membranes were polypropylene hollow fibers with a nominal pore size of 0.2 µm. Filtration took place from he shell side to the lumen side in a dead end mode operation. Solids retained by the membrane (cake layer) were periodically removed using high-pressure air (600 kPa) back washing. During the backwashing pressurised air was forced from the lumen side to the shell side to dislodge the cake layer, which was washed away with a small amount of feed water. Trials were carried out with the secondary effluent (average SS = 40 mg/L) at constant flux. The fluxes examined were in the range of 30 to 90 $L/m^2.h$. Backwashing process was initiated when the Transmembrane pressure (TMP) reached a specified value (20 or 50 kPa). Runs were typically 4 to 6 hours duration involving multiple cycles of filtration and backwash. At the end of each run the membrane was chemically cleaned by an alkali cleaning solution provided by the membrane manufacturer.

Operational data obtained from the pilot plant and data from other sources were used to carry out a Life Cycle Assessment (LCA) of the membrane process at different operating conditions.

RESULTS AND DISCUSSION

Transmembrane Pressure (TMP)

Typical transmembrane pressure profiles at high imposed flux of 81 $L/m^2.h$ and low imposed flux of 30 $L/m^2.h$ are shown in Fig.1 for MF of the secondary effluent with TSS of about 40 mg/L. The TMP at which the air backwash was actuated was 20 kPa. At an imposed flux of 30 $L/m^2.h$ the air backwash appears to be very effective at foulant removal. The back washed membrane recommences each cycle at almost the same low TMP although this value tends to increase slowly as a gradual accumulation of foulant still occurs over time. However with an increase in imposed flux it is more and more difficult to restore the starting TMP to the low value during subsequent cycles. This means that the imposed flux influences the initial transmembrane pressure (ΔP_i) in subsequent cycles. For example, for an imposed flux of 81 $L/m^2.h$, the starting TMP can be seen to rise rather quickly. It was also be observed from the trials that chemical cleaning at the end of each trial was able to restore the starting TMP to about 3-5 kPa regardless of the imposed flux. Consequently it may be concluded that operating at higher flux will require more frequent chemical cleaning of membranes, which potentially reduces the membrane life as well as increasing the environmental impact of the process.

Backwash Interval and Net Flux

Fig. 2 shows the variation of cycle time with the flux. The time for one cycle i.e. time for TMP increase to 20 kPa (backwash interval) was strongly dependent on the imposed flux as expected. Fig. 2 also shows the net flux (total permeate in a cycle/cycle duration + air backwash duration), which allows for the effect of time off-line due to backwash. Net flux is significantly less than imposed flux at higher flux conditions. For example the net flux is 71 $L/m^2.h$ (79 % of the imposed flux) for 90 $L/m^2.h$ imposed flux, whereas at 30 $L/m^2.h$ imposed flux it is 29 $L/m^2.h$ (97 % of the imposed flux). This is due to the 20 times higher frequency of back washing at 90 $L/m^2.h$ imposed flux compared to that at 30 $L/m^2.h$ imposed flux (every 5 minutes vs every 100 minutes).

Energy Demand and Cost Assessment

Fig. 3 shows the relationship between the imposed flux and the net flux and the frequency of blowbacks. As imposed flux increases the net flux increases, but more slowly and the blowback frequency increases dramatically. In such a process there will be a trade-off between capital and operating (energy/chemical) cost. For example, an imposed flux of about 30 to 35 $L/m^2.h$ will require slightly more than double the membrane area of an imposed flux of about 90 L/m^2.h for the same production rate (at TMP_{max} of 20 kPa). However the imposed flux of 30 to 35 L/m^2.h will require an order of magnitude less energy for backwash (Fig. 4). It should also be noted that the energy demand for air backwash is much higher than that of the feed pump. These energy calculations show that operation at lower flux will require significantly less total energy for both feed pump and air compressor in terms of kWh per cubic meter effluent filtration. When the unit was operated with a maximum TMP of 50 kPa, the energy demand for the pump increased proportionately to that required at 20 kPa maximum TMP (about 3 times higher) for all imposed fluxes. However the energy required for back washing was lower, due to less frequent backwashes, and its increase with imposed flux also slower (Fig. 4).

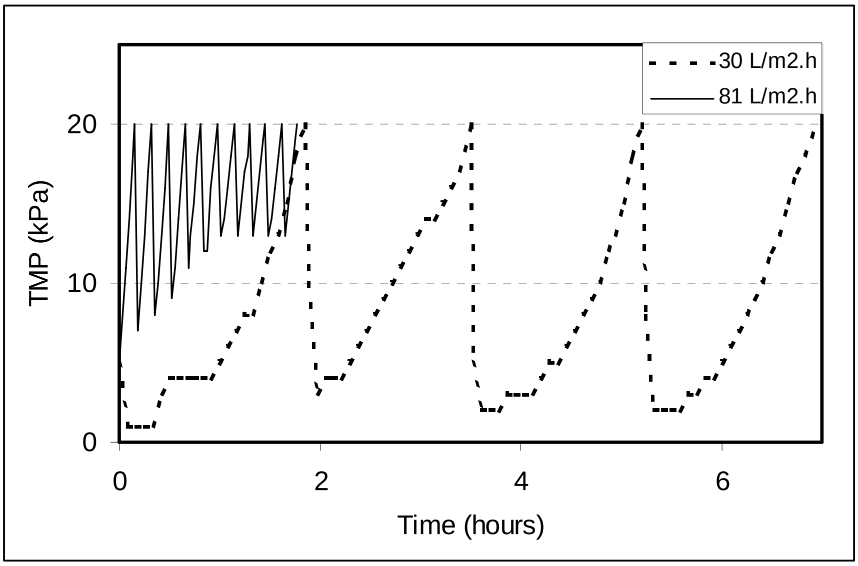

Fig. 1 Typical TMP profiles (TSS ≈ 40 mg/L)

In this preliminary cost assessment we examine the trade off between capital and operating cost to demonstrate the potential for optimal (economic) operating conditions. The variation of energy cost and energy + capital cost with the imposed flux are shown in Fig. 5. For a maximum TMP of 20 kPa the energy + capital reaches a minimum when the plant operates at an imposed flux between 60 and 70 L/m^2.h. For a maximum TMP of 50 kPa, the energy + capital cost reach a minimum after an imposed flux of about 80 L/m^2.h. The lower cost minimum for higher TMP is because the backwash frequency is reduced. However the analysis does not allow for the probable increase in chemical cleans and reduced membrane lifetime of a higher imposed flux. It should also be noted that the foregoing assessment indicates that the minimum cost strategy will not be the minimum energy strategy. Our analysis should provide an indication of the apparent economic penalty for energy saving.

Impact to the Environment and Fresh Water Bodies

The above conventional economic analysis implies that lower flux, energy saving strategies, are sub-optimised. However this type of analysis fails to incorporate diseconomies due to environmental impact. To address this a total life cycle assessment was carried out to identify the impacts to the environment by different operating conditions. It can be noted from previous discussions that low energy demand operation requires more membrane area. This means there is an embodied energy in the membrane plant. By carrying out life cycle analysis this can be accounted for. Our analysis indicates that the electricity usage is the single largest contributor for all the environmental impacts. For example between 89% (at 10 L/m^2/h flux) and 99% (at 100 L/m^2/h flux) of the global warming potential impacts of filtration process come from the electricity usage. Similarly for the Eutrophication impact category, electricity usage contributes between 83 and 98% of the impact. Here the electricity usage means the electricity used for the plant operation as well as electricity usage during the module manufacturing, chemical manufacturing etc.

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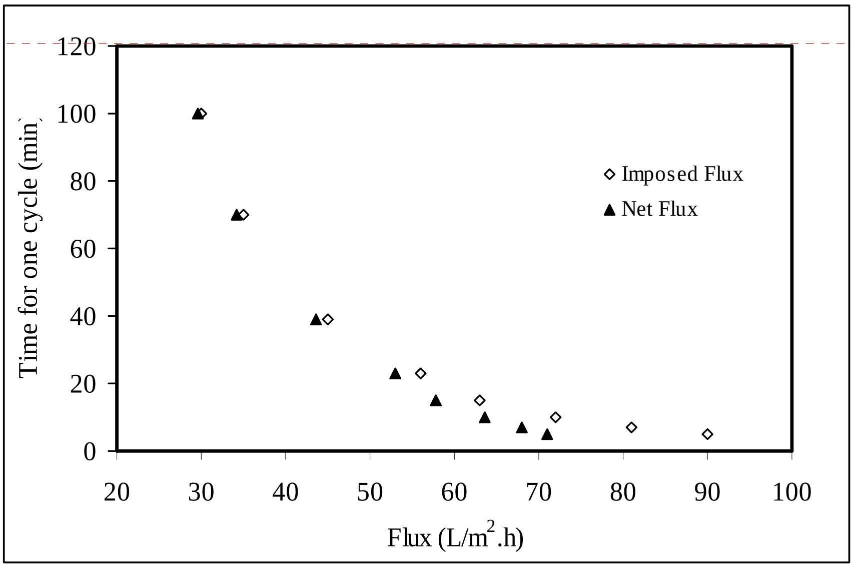

Fig. 2 Cycle time variations with Imposed and Net Fluxes

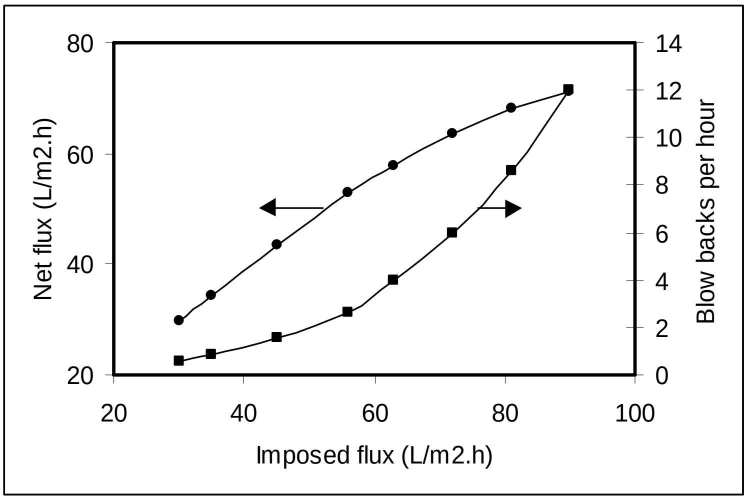

Fig. 3 Relationship between imposed flux, net flux and frequency of backwash

Figure 6 shows a typical example of embodied and apparent energy consumption in the process (TMPmax = 20 kPa). Based on this total life cycle assessment the minimum energy condition is achieved when the plant is operated at 20 L/m^2.h imposed flux (total life cycle energy of 609

MJ/ML vs. the apparent energy of 142 MJ/ML). Apparent energy is the amount of energy measured as the input to operate the plant and includes pump and compressor energy. Total life cycle energy includes the energy required to manufacture the membrane plant, the chemicals used in it as well as the apparent energy and the energy required to produce the above energy (energy usage from the sourcing of the materials). Overall environmental impact ranking of all the cases (Table 1), based on the life cycle assessment results, shows low imposed flux with a high TMPmax operation has the least impact on the environment. As shown in Table 1, the impact on the fresh water ecology and the eutrophication potential are also reflected in the overall ranking. This is mainly because most of the environmental impact is contributed by the operation stage (from 87% to 98%) rather than from setting up the plant and our heavy reliance on coal as our primary energy source. Based on total environmental impact the optimal flux drops to 10 to 20 L/m^2.h, which is substantially lower than the >80 L/m2.h obtained from strict economic assessment. These observations would lead to a radical change in the specification of membrane technology for sustainable water reclamation. In the context of river health we need water reclamation and we need it to be environmentally sustainable. Further analysis is required to determine how the flux optima would shift if the energy was provided by an alternative source such as solar power.

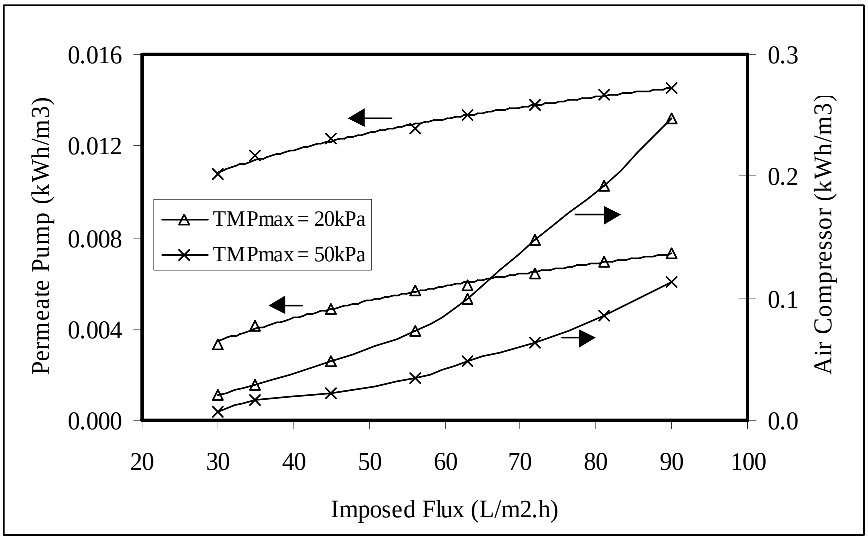

Fig. 4 Energy consumption by permeate pump and air backwash

CONCLUSIONS

Water reclamation can have important benefits for river health. Membrane technology provides a key to effective purification of effluents, but needs to be operated optimally. In the case considered, namely MF of treated effluent, an analysis based on energy and capital cost indicates that if energy saving is the objective the unit needs to be operated at low imposed flux. Similar conclusion can be drawn if environmental impact is the major concern with an LCA analysis leading to fluxes of 10 to 20 L/m^2.h. However if capital and energy costs were combined, cost efficient operation would be at about 60 to 70 L/m^2.h for TMP$_{max}$ of 20 kPa or above 80 L/m^2.h for TMP$_{max}$ of 50 kPa. Thus the operating strategy depends on whether the aim is to operate for energy saving and low environmental impact or total cost saving. There is a capital cost penalty and larger plant size for energy saving and lower environmental impact. But the simple economic analysis does not consider the environmental cost. Considering the fact that our river systems and the environment are under severe threat, it is advisable to operate at the low imposed flux condition. However to encourage this strategy it will be necessary to influence the economics. For example, if the capital cost of the microfiltration system could be subsidised from different sources (such as an environmental credit scheme), low imposed flux would become attractive in terms of simple economics. This will reduce recycled water costs and encourage reuse and protection of our environment. In both environmental and economic analysis the results favor the high TMP operation. However in membrane point of view and our in depth analysis indicates, operating at high TMP is not favored. This also needs to be optimised.

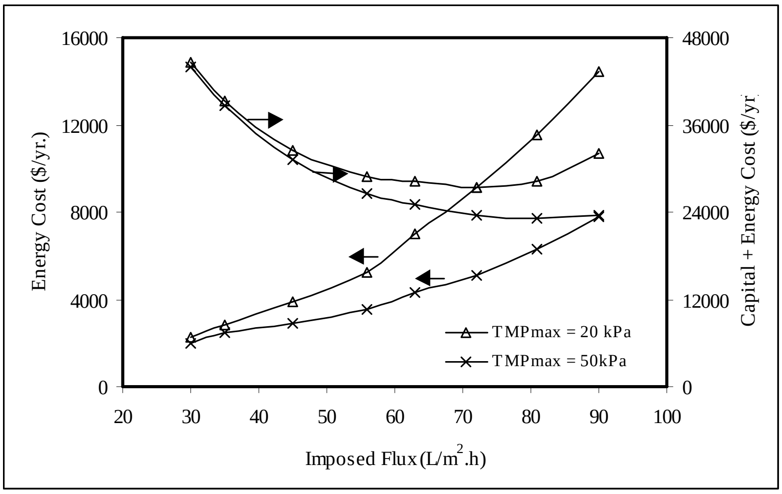

Fig. 5. Capital and Energy costs

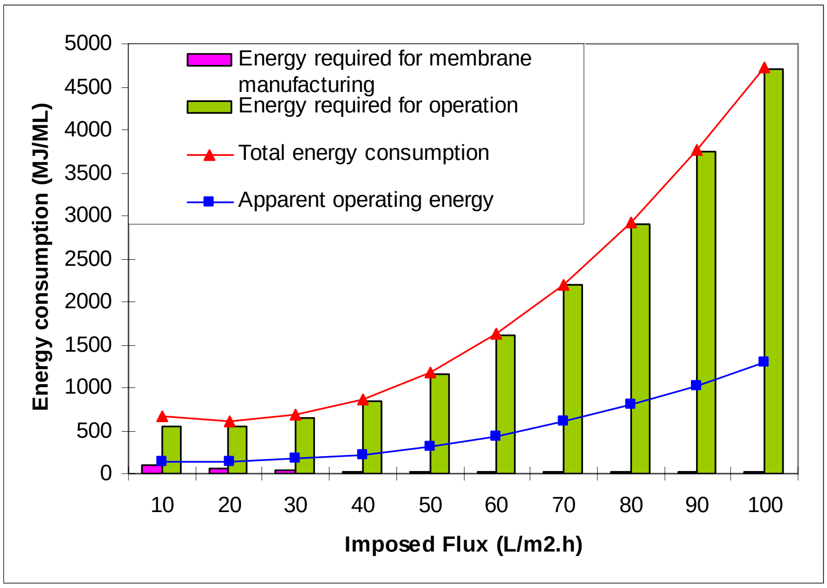

Fig. 6 Embodied and apparent energy consumption (TMPmax = 20 kPa)

Table 1 Environmental Impact Ranking

Imposed Flux (L/m2.h)	Ranking base on Eutrophication Potential		Ranking based on Impact to Fresh Water Ecology		Overall Impact Ranking	
	TMP$_{max}$ 20 kPa	TMP$_{max}$ 50 kPa	TMP$_{max}$ 20 kPa	TMP$_{max}$ 50 kPa	TMP$_{max}$ 20 kPa	TMP$_{max}$ 50 kPa
10	3	1	5	1	4	1
20	4	2	4	2	3	2
30	6	5	6	3	6	5
40	8	7	9	7	8	7
50	11	9	11	8	11	9
60	13	10	14	10	13	10
70	16	12	16	12	16	12
80	18	14	18	13	18	14
90	19	15	19	15	19	15
100	20	17	20	17	20	17

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REFERENCES

Adham S., Trussell R., Gagliardo P., Weibberg K. and Richardson T. (1997) Development of an innovative advanced treatment system for indirect potable reuse. *Proceedings IDA World Congress on Desalination and Water Reuse Vol. II*, Madrid, Spain, October 6-9. pp. 503-507

Barr K. (2002) Operating a water reclamation plant to convert sewage effluent to high quality water for industrial reuse. *Proc. IWA 3rd World Water Congress*, Melbouure, Australia, 7-12 April 2002.

Conklin S.R., Dunivin W.R., Herberg J.D. and Leslie G.L. (1996) Advanced Treatment Using Microfiltration and Reverse Osmosis Reclaim Secondary Effluent in Orange County California. *Proceedings of the 16th Federal Convention Australian Water and Wastewater Association*, Sydney, Australia, May 27-28, 1996.

Cooney E. (2001) Water reclamation plant a green winner for Olympic site. *Proc. Aust Water Assn 19th Federal Convention*, Canberra, April 2001.

Cooper E. (2003) Rouse Hill and Picton Reuse Schemes: innovative approaches to large-scale reuse. *Water Science and Technology:Water Supply* **3(3)** pp 49-54.

Defrance L. and Jaffrin M.Y. (1999) Reversibility of fouling formed in activated sludge filtration. *J. Memb. Sci.* **157(1)**, 73-84.

Leslie, G.L., Mills, W.R., Dunivin, W.R., Wehner, M.P. and Sudak, R.G. (1998). Performance and economic evaluation of membrane processes for reuse application. *Proc. of Wat. Reuse Conf.*, LakeBuena Vista, FL, USA.

Masson M and Deans G. (1996) Membrane filtration and reverse osmosis purification of sewage: secondary effluent for reuse at Eraring power station, *Desal.* **106**:11-15.

Parameshwaran K, Fane A.G., Cho B.D. and Kim K.J. (2001) Analysis of microfiltration performance with constant flux processing of secondary effluent, Wat. Res. 35(18):4349-4358.