

MEMBRANE BIOREACTORS : WASTEWATER TREATMENT APPLICATIONS TO ACHIEVE HIGH QUALITY EFFLUENT



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MEMBRANE BIOREACTORS: WASTEWATER TREATMENT APPLICATIONS TO ACHIEVE HIGH QUALITY EFFLUENT

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ABSTRACT

Membrane bioreactors (MBRs) combine the use of biological processes and membrane technology to treat wastewater. Within one process unit, a high standard of treatment is achieved, replacing the conventional arrangement of aeration tank, settling tank and filtration that generally produces what is termed as a tertiary standard effluent. The dependence on disinfection is also reduced, since the membranes with pore openings, generally in the 0.1-0.5µm range, trap a significant proportion of pathogenic organisms. The more common MBR configuration is to have the membrane immersed in the wastewater, although a side stream configuration is also possible, with the wastewater pumped through the membrane module and then returned to the bioreactor. Operating at a mixed liquor suspended solids (MLSS) concentration of up to 20,000 mg/L and a sludge age of 30-60 days, MBRs offer additional advantages over conventional activated sludge plants, including a smaller footprint.

KEY WORDS

Membranes; membrane bioreactors; activated sludge; disinfection; tertiary effluent.

1.0 INTRODUCTION

As community awareness of the impacts of discharging treated effluent to the environment increases, so is the need to improve the performance of existing treatment plants. Not only does a high effluent quality reduce negative impacts of discharging a treated effluent to inland waterways, but the range of possible reuse options is wider when a high quality effluent is available.

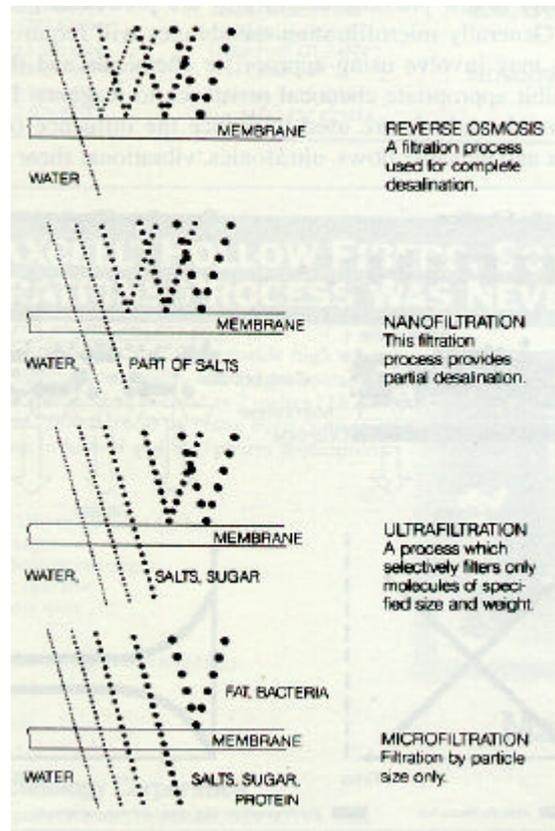
In Victoria the requirements for the quality of effluent to be discharged to inland waters are summarised in Table 1 (EPA, 1995).

Table 1: *Standards for discharge to inland waters.*

Indicator	Unit	Median	90 percentile
BOD	mg/L	5.0	10.0
SS	mg/L	10.0	15.0
Ammonia – N	mg/L	2.0	5.0
Total N	mg/L	10.0	15.0
Total P	mg/L	0.5	1.0
Ecoli	orgs/100mL	200.0	1000.0

At many existing treatment plants producing a standard secondary effluent (20mg/L BOD, 30mg/L SS), add-on processes have been constructed to achieve this tertiary effluent. Designers and constructors of new plants face similar pressures in obtaining regulatory agency approval for discharge of treated effluent, other than where land reuse is proposed.

An option that may be considered in order to achieve additional treatment of sewage effluent is membrane technology. The use of membrane technology for effluent treatment may be appropriate and superior to that of existing process options. However, there are situations where membranes



There has been significant research and development in recent years that has advanced MBR technology to a position where all of the above concerns have been addressed. The use of MBRs has progressed in parallel with this development from laboratory scale through to full-scale application of up to 13,000m³/d. Commercial MBR systems have now been operational for many years and have proven both reliable and simple to operate. Membrane failure rates have proven to be low and increased scale and performance of the systems has resulted in reduced capital and operational costs. This, coupled with increased focus on water re-use and the need to achieve higher discharge standards, in order to satisfy legislation, means that the use of MBR technology is becoming a realistic option for advanced effluent treatment.

2.0 CONFIGURATION OF MBR SYSTEMS

In an MBR, membrane filtration occurs either within the bioreactor (submerged configuration, Fig. 3 (a)) or externally through recirculation (Fig. 3 (b)), subject to a pressure drop across the membrane driven by either the hydraulic head or a pump. The UF or MF membranes utilized by MBRs have pore sizes such that water and most solute species pass through the membrane whilst other larger species, such as solids and microorganisms, are retained. The choice between operating options is dependent upon the application, as both systems have advantages and disadvantages (Table 2).

Aeration within the bioreactor provides the required oxygen transfer for growth of the biomass and mixing of the reactor. In the submerged configuration a coarse bubble diffuser is generally used. This system does not offer very efficient oxygen transfer but the rising bubbles provide a turbulent crossflow velocity (approximately 1 m/s) over the surface of the membrane. This helps to maintain the flux through the membrane, by reducing the build up of material at the membrane surface, and thereby increases the operational cycle of the system.

Figure 3: (a) Side stream MBR configuration with a separate membrane filtration unit; (b) submerged MBR configuration with membrane unit integrated into the bioreactor.

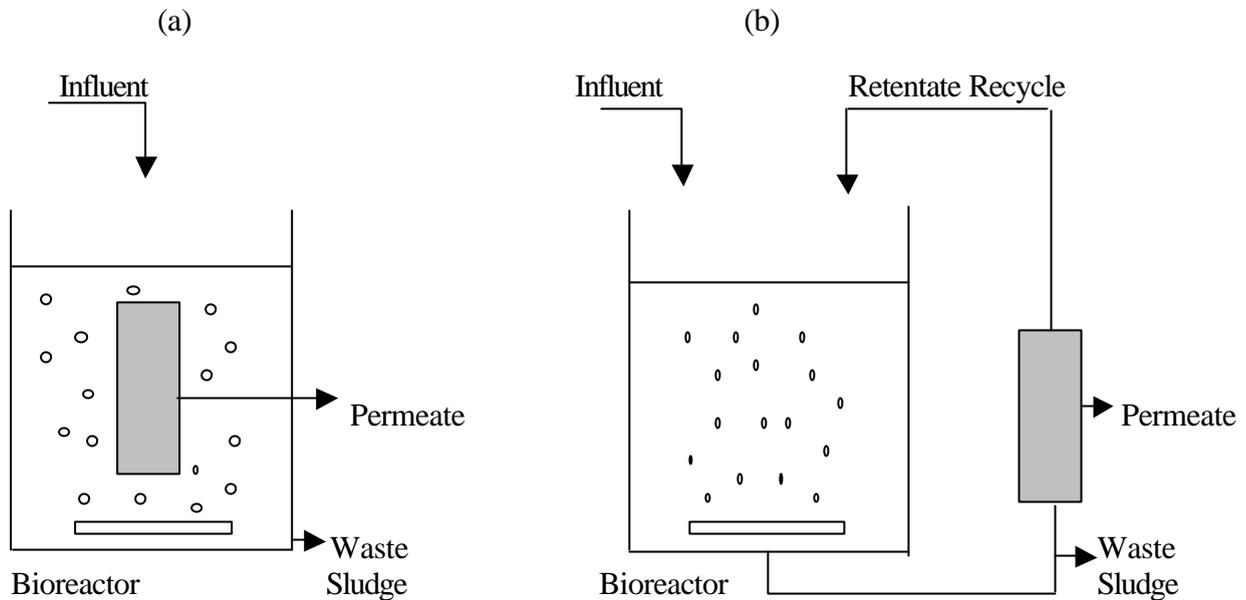


Table 2: *Advantages and disadvantages of MBR configurations.*

Submerged MBR	Side-Stream MBR
Aeration costs high (~90%)	Aeration costs low (~20%)
Very low liquid pumping costs (higher if suction pump is used ~28%)	High pumping costs (60-80%)
Lower flux (larger footprint)	Higher flux (smaller footprint)
Less frequent cleaning required	More frequent cleaning required
Lower operating costs	Higher operating costs
Higher capital costs	Lower capital costs

Less frequent and less rigorous cleaning of the membrane is required to restore operational flux compared to the side stream system. In the side stream systems the aeration is usually through a fine bubble diffuser, which offers much more efficient oxygen transfer. The crossflow velocity utilized in these systems is usually higher (2-4 m/s). As the system is driven by a differential head, the operational flux of the system is higher. The disadvantage of this is that fouling of the membrane is more pronounced and much more rigorous cleaning regimes are required to restore the operational flux. The useful life of the membrane may be reduced by such an operating regime.

3.0 DISCUSSION

A comparison of the organic loading rates and removal efficiencies of varying unit treatment processes is presented in Table 3. It is seen that MBRs offer a system that competes very effectively with conventional treatment processes. The organic loading rates are generally higher than trickling filters, sequencing batch and conventional activated sludge process (ASP), due to shorter HRT, but lower than BAFs, complete-mix and high rate ASP.

Table 3: *Organic loading rates for treatment processes (Gander et al., 2000).*

Reactor	Organic Loading rate (kg BOD ₅ .m ⁻³ .d ⁻¹)	HRT (h)	Percentage Removal
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BAE: Downflow Downflow Upflow	1.5 (COD) 7.5 4	1.3 - -	93 75 >93
TE: Low Rate Intermediate High rate	0.08-0.4 0.24-0.48 0.48-0.96	- - -	80-90 50-70 65-85
ASP: Sequencing Batch Conventional Complete Mix High Rate Aeration	0.08-0.24 0.32-0.64 0.8-1.92 1.6-16	12-50 4-8 3-5 2-4	85-95 85-95 85-95 75-90
MBR: Submerged: Plate & Frame (Kubota) Hollow Fibre (Tech Sep) Plate & Frame Hollow Fibre Side Stream: Ceramic Plate & Frame	0.39-0.7 0.03-0.06 0.005-0.11 1.5 (COD) 0.18 0.45-1.5 (COD)	7.6 1 8 0.5 24>95 8	99 98-99 98 87-95 - 88-95

One of the main features of MBR technology is the ability of the membrane to remove pathogenic organisms, providing disinfection of the effluent. This is particularly important when considering reuse options. The membrane offers a physical barrier to the organisms that is unaffected by the influent quality. Reductions in bacteria and viruses of 4 –8 log. have been reported (Kolega *et al.*, 1991; Chiemchaisri *et al.*, 1992; Gander *et al.*, in press; Jefferson *et al.*, 1998) (Table 4).

Table 4: Reduction in microorganisms using different membrane systems.

Membrane	Pore Size (mm)	Average Log Reduction	Bacteria/ Virus	Reference
MBRs:				
PE ⁽¹⁾	0.1	4-6	Coliphage QB	Chiemchaisri <i>et al.</i> (1992)
PS ⁽¹⁾	0.5	5	TC	Gander <i>et al.</i> (in press)
PS ⁽¹⁾	0.3	ND	TC	Jefferson <i>et al.</i> (1998)
Memtec ⁽²⁾	0.2	ND	TC	Kolega <i>et al.</i> (1991)
Memcor ⁽²⁾	0.2	3.8	FC	Till (1998)
Renovexx ⁽²⁾	0.5-1.5	3.3	FC	Till (1998)
Stork ⁽³⁾	0.05-0.2	2.5	FC	Till (1998)
Starcosa ⁽³⁾	0.2	ND	TC	Till (1998)
DOW ⁽³⁾	0.2	<7	TC	Till (1998)

(1) Activated sludge within MBR; (2) Primary sewage effluent; (3) secondary sewage effluent.
ND – None Detected; TC –Total Coliforms; FC – Faecal Coliforms

The advantages offered by MBRs over the conventional activated sludge process (ASP) include a smaller footprint and reduced sludge production. MBRs can be operated at MLSS of up to 20,000 mg/L and as sludge settling is not required, submerged MBRs can be up to 5 times smaller than a conventional ASP. The high biomass concentration in the MBR tank allows complete breakdown of carbonaceous material and nitrification of municipal wastewater to be achieved within an average retention time of 3 hours. The fact that clarification is achieved in a single filtration stage, in place of the conventional multi-stage process, also contributes to the smaller footprint. If additional denitrification is required for the system a second anoxic tank can be

provided prior to the aeration tank with conventional recycle.

Sludge production is significantly reduced, compared to conventional ASP, as longer sludge ages are achievable (Table 5) (Mayhew and Stephenson, 1997). Since sewage sludge disposal contributes significantly to overall operating costs, there are significant potential benefits in reducing its production.

Table 5: *Sludge production for various wastewater treatment processes (Mayhew and Stephenson, 1997)*

Treatment Process	Sludge production (kg/kgBOD)
Submerged MBR	0.0-0.3
Structured media biological aerated filter (BAF)	0.15-0.25
Trickling filter	0.3-0.5
Conventional activated sludge	0.6
Granular media BAF	0.63-1.06

4.0 COMMERCIAL MBR SYSTEMS

The two main suppliers of MBR systems for wastewater treatment are Kubota (Japan) and Zenon (USA). Other suppliers are Degremont (France), Membratek (S. Africa), Orelis/Mitsui (Japan), US Filter (USA) and Wehrle Werk (Germany).

4.1 Kubota

Kubota uses a flat sheet membrane made of polyolefin with a non-woven cloth base giving a nominal pore size of 0.4µm. Each membrane cartridge consists of solid acrylonitrile butadiene styrene (ABS) support plate with a spacer layer between it and an ultrasonically welded flat sheet membrane on both sides. The typical membrane cartridge (Type 510) has dimensions of 1.0m (H) x 0.49 (W) x 6mm thick – filtered water passes through to the interior of each membrane to an outlet nipple cast into the top of the support plate. Each cartridge provides an effective filtration area of 0.8m².

The Kubota MBR operates with membrane treatment units submerged in the reactor in which the MLSS is maintained within the range of 15,000 to 20,000mg/L. The standard Kubota unit has a glass fibre reinforced plastic casing and consists of 2 sections. The upper section contains up to 150 membrane cartridges, each connected to a filtered effluent manifold with a gap of approximately 7mm between cartridges. The lower section is a matching unit containing a coarse bubble diffuser. The lower section supports the upper section and directs the mixture of air bubbles and mixed liquor between the membrane cartridges in the upper section. This air-water mixture maintains an upward cross flow over the membrane surface of approximately 0.5m/s, minimising fouling of the membranes. The minimum air requirement is 10L/min.cartridge.

The Kubota system operates by gravity, with a head of 1-1.5m above the membranes sufficient to drive permeate through the membranes. Grit removal and fine (2-3mm) screening are pre-requisites prior to the MBR. The membrane flux for the Kubota system is approximately 20L/m².h (submerged system at a TMP of ~0.1bar).

Chemical cleaning of the membranes is required every 3-6 months using sodium hypochlorite and oxalic acid. Cleaning requires 3L of chemical solution per cartridge and the cleaning cycle takes up to 2 hours.

Kubota has a reference list of over 400 plants treating domestic and industrial wastewater, with most of the sites located in Japan. The Kubota plants range in size from systems to treat the equivalent of individual households to the 23,000 EP (5,800m³/d ADWF) plant at Swanage in the

south of England. The Kubota technology is to be utilised at a new MBR plant (2,000 EP) to be built at Magnetic Island in Queensland.

4.2 Zenon

Zenon markets the ZenoGem system, based on the ZeeWeed membrane, which is a hollow fibre with an external diameter of 1.9mm and a nominal pore size of 0.4µm. The fibres are mounted on vertical frames into modules with filtered effluent passing into the centre of the fibre and extracted from both ends. The ZW-500 module is 2.0m (H) x 0.7m (W) x 0.2m thick with 46m² of filtration surface area. Cassettes are made up of 8 modules each. Air is supplied to the system by a combination of coarse bubble aerators integrated into the bottom header of modules, to gently agitate the membrane fibres and to keep the tank contents mixed, and by fine bubble aeration to supply the balance of the total biological oxygen demand.

The filtration capacity is in the range of 40-70L/m²h under a driving transmembrane pressure of 10-50kPa. This pressure is provided by the head of water over the membranes and by maintaining a negative pressure on the permeate side using conventional centrifugal pumps. Sludge wastage is claimed to be 1.5-2.0% of the influent flow.

ZenoGem biological design parameters are:

- ◆ MLSS 15,000-20,000mg/L
- ◆ F:M < 0.2kg BOD/kg MLSS.d
- ◆ Volumetric Loading 1.8-5.7kg BOD/m³.d
- ◆ HRT > 2 hours
- ◆ SRT > 15 days
- ◆ Flux 15-25 L/m².h (TMP of ~0.5 bar)

In addition to the scouring action of the coarse bubble aeration, cleaning of the membranes to control fouling is provided by automatic pulses of backwashing with stored permeate and periodic in-situ membrane cleaning with a hypochlorite solution or other chemicals.

Zenon has a reference list of over 150 plants treating domestic and industrial wastewater. Zenon is represented in Australia by John Thompson Australia.

5.0 CONCLUSIONS

- ◆ Effluent quality is consistently high and generally independent of the influent quality.
- ◆ Good disinfection capability, with significant bacterial and viral reductions achievable using UF and MF membranes.
- ◆ Longer retention of nitrifying bacteria within the bioreactor results in greater nitrification than in a conventional ASP. Denitrification can be achieved by utilizing a second anoxic vessel.
- ◆ Long sludge ages result in lower sludge production.
- ◆ Small footprint technology.
- ◆ Proven reliability and easy operation.

6.0 REFERENCES

- Chiemchaisri, C., Womg, Y. K., Urase, T. and Yamamoto, K. (1992). *Organic stabilisation and nitrogen removal in membrane separation bioreactor for domestic wastewater treatment. Water Science and Technology*, 25 (10), 231-240.
- Environment Protection Authority (1995) *Managing Sewage Discharges to Inland Waters, Publication 473*. Published by Environment Protection Authority, State Government of Victoria. ISBN 0 7306 7501 7.
- Gander, M., Jefferson, B. and Judd, S. (2000). *Aerobic MBRs for domestic wastewater treatment: a review with cost considerations. Separation and Purification*, 18, 119-130.
- Gander, M., Jefferson, B. and Judd, S. (1999). *Membrane bioreactors for use in small wastewater treatment plants: membrane materials and effluent quality. Water Science and Technology*, in press.
- Jefferson, B., Laine, A., Brindle, K., Judd, S. and Stephenson, T. (1998). *Proceedings of Water Environment '98: Maintaining the Flow*, London 26th March 1998.
- Kolega, M., Grohman, G. S., Chiew, R. F. and Day A. W. (1991). *Disinfection and clarification of treated sewage by advanced microfiltration. Water Science and Technology*, 23 (7-9), 1609-1618.
- Mayhew, M. and Stephenson, T. (1997). *Environmental Technology*, 18, 883-886.
- Till, S. (1998). *Crossflow microfiltration of sewage effluents*. PhD Thesis, Cranfield University, UK.