# MEMBRANE TECHNOLOGY IN WASTEWATER TREATMENT: TERTIARY MEMBRANE FILTRATION (TMF) SYSTEMS, AN ECONOMICALLY ATTRACTIVE ALTERNATIVE TO MEMBRANE BIOREACTORS (MBR)

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## INTRODUCTION

The use of membranes for treating wastewater is now widespread. Membrane bioreactors (MBRs) have rapidly emerged as a key technology for both industrial and municipal wastewater treatment due to their ability to deliver high final effluent water quality and their relatively small footprint as compared to a conventional Activated Sludge (AS) process. The costs of MBRs have fallen by almost a factor of 10 in the last decade driven by technical improvements (e.g. higher fluxes, longer membrane lifetimes, lower aeration requirements) and by economies of scale. We have now reached the point where the capital costs for MBR systems are fairly competitive with conventional systems (AS) systems, particularly where land acquisition is expensive. This combination of high quality effluent and reasonable capital costs coupled with over ten years experience demonstrating reliable operation has lead to the installation of around 4000 MBR systems worldwide, with many systems now treating flows in excess of 1 MGD (4 MLD) and some above 10 MGD (40 MLD).

A general schematic of a conventional AS system is shown in Figure 1 and an MBR is shown in Figure 2.When compared side by side it is clear that the MBR appears simpler and certainly occupies less footprint.

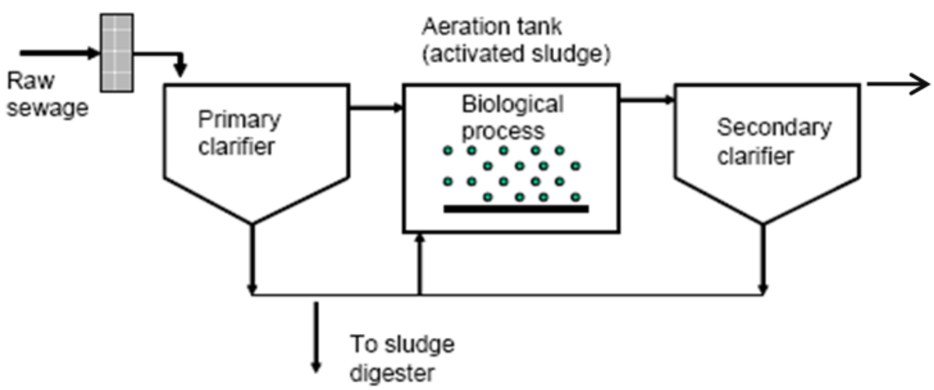



**Figure 1: Conventional Activated Sludge Process**

The vast majority of MBRs are configured with the membranes submerged in an activated sludge basin (as show in the figure). Permeate is drawn through the membranes by applying a small suction on the filtrate side. Both UF and MF types of membranes have employed with very little practical difference between the two. Various membrane materials have been used and PVDF and PES tend to be the major choices. The dominant configurations are either flat sheet (plate and frame) or hollow fiber. Each material and each configuration has its own plusses and minuses but in general all can perform well when properly designed and operated.

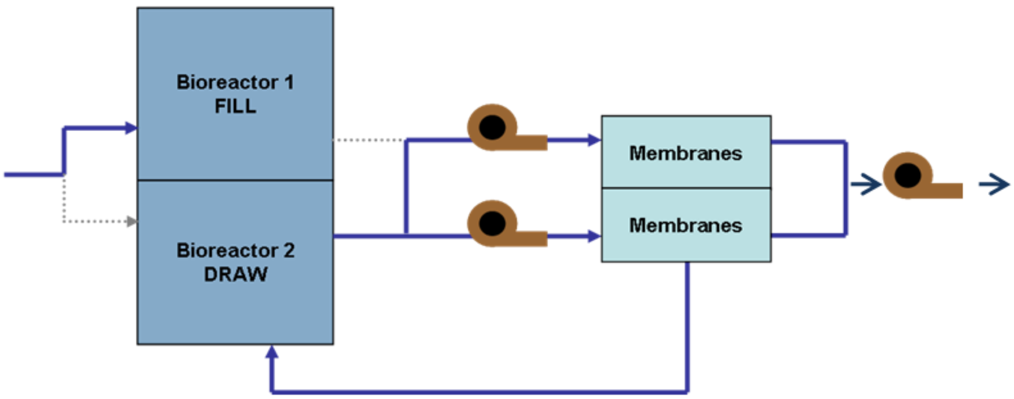



**Figure 2: Aqua-Aerobic MBR schematic**

An example of one of the most successful applications of MBR technology is the expansion of existing activated sludge plants to increase their capacity without building new tanks or requiring any additional space. This can be achieved because MBRs operate at higher mixed liquor concentrations than conventional activated sludge processes and yet still remove suspended solids because all of the effluent must pass through the membranes. Retrofitting is a particularly economically attractive option when an existing facility requires a flow upgrade.

Tertiary Membrane Filtration (TMF) using either UF or MF is often a very good alternative to MBR. Like MBR tertiary membrane treatment offers membrane-quality effluent but often with lifecycle costs of 30% to 50% of those of MBR technology. A schematic of a Tertiary system incorporating headworks, sequencing batch reactors and cloth media filters followed hollow fiber membranes is shown in Figure 3 courtesy of Aqua Aerobic Systems Inc. Tertiary membrane filtration systems have been employed in hundreds of waste water applications for many years though they have not enjoyed the headline publicity of the MBRs. The TMF systems require more land area (footprint) than the MBR but the TMF usually requires less than half the membrane area and this is a major contributor to the overall life cycle cost savings.

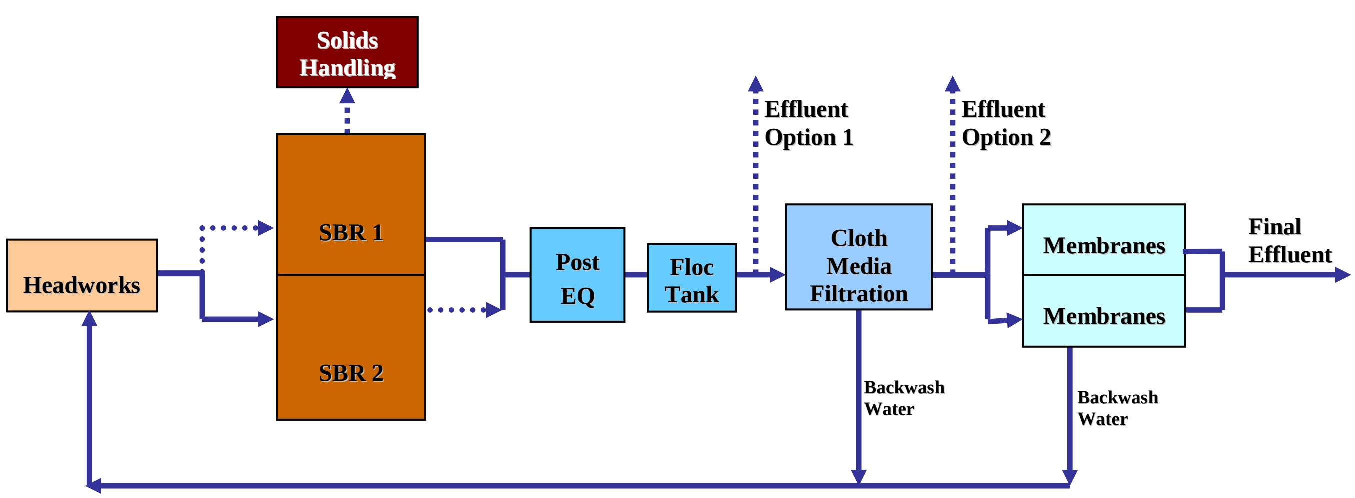


**Figure 3: Tertiary Membrane Treatment Process Flow Schematic**

A key advantage of the TMF approach is that the system is configured as a series of unit processes which therefore provides a Multi-Barrier Treatment Process (MBTP). The MBTP approach provides various levels of treatment depending on from where in the process the effluent is removed. It is not always necessary to filter all of the water through the membranes all of the time. Thus the operator is enabled to selectively discharge effluent directly from the sequencing batch reactor (SBR), or the cloth media filter (CMF) or from the membrane system.

The ability to select the take off point for the effluent potentially can save money for example in cases where discharge permits are seasonal and require different quality parameters based upon summer or winter months or flood conditions compared to dry conditions. Similarly in locations where the waste water quality varies seasonally and the full range of treatment is not always required or where the flow rate varies widely and therefore the level of treatment required is allowed to be adjusted. As noted earlier when employing an MBR system all of the flow must necessarily pass through the membranes, thus the MBR system must be designed with enough membranes to treat the peak flow even if the peak flows are infrequent or occur at a time when removal of small particles is not critical. By contrast, with the MBTP concept the operator can elect to operate the membranes on an as-needed basis (in effect the membranes may be by-passed yet the plant still produces SBR treated water) therefore the potential to design a more cost effective system exists.

## CASE STUDY

### Background

An MBTP system was installed at the St. Helens WWTP in Tasmania, Australia in May 2008 and provides a good example of where a TMF was chosen rather than an MBR, though either approach could have potentially provided a technical solution. The plant is designed to treat a 1.5 mega-liter (0.4 million gallon) per day average dry weather domestic sewage flow from the local community. The flows and loadings vary seasonally dependent in part on the influx of tourist. The plant that discharges into a bay which is also used for oyster farming so the treatment objectives include Suspended Solids, BOD, Nitrogen and Phosphorus reduction and disinfection. The design parameters are summarized in Table 1.

| Parameter | Design Influent | Effluent Required |
|---|---|---|
| Average Flow (MGD) | 0.4 | -- |
| Maximum Flow (MGD) | 0.8 | -- |
| $BOD_5$ (mg/L) | 230 | 2 |
| TSS (mg/L) | 150 | 4 |
| TKN (mg/L) | 52 | -- |
| $NH_3$-N (mg/L) | -- | 0.7 |
| Total Nitrogen (mg/L) | -- | 7 |
| Total Phosphorus (mg/L) | 10 | 1 |

**Table 1: St. Helens Key Design Parameters**

## Plant / Process Description

The St. Helens plant consists of an influent pump which pumps the wastewater to a grit removal system and a 6mm aperture-perforated inlet screen. The water flows from the screens to one of the two sequencing batch reactors (SBRs) which provide the main activated sludge and settlement processes. The clarified effluent from the SBRs is received by an effluent equalization (or Post-EQ) tank and from there flows to a flocculation tank and under gravity to a nominally rated 10µ cloth media filter. The tertiary effluent is then pumped to a TMF (a hollow fiber membrane system) and finally to a UV disinfection system. The plant also incorporates aerobic sludge digestion.

Aluminum sulfate (alum) is dosed into the biological reactors and/or into the flocculation tank for enhanced phosphorus removal.

Sodium carbonate is available to increase the alkalinity in the biological reactors to compensate for the alkalinity that is consumed by the coagulation reactions. Chemicals for membrane cleaning processes include citric acid, sodium hydroxide, and sodium hypochlorite.

The cloth media filter is automatically backwashed and the backwash water is returned to the headworks.

The membrane system incorporates several cleaning methods, the primary method being backwash and the secondary methods include chemical soaking. The waste water is also returned to the headworks.

**Figure 4: The St. Helens WWTP during construction**

**Figure 5: Internal components of the SBR Tank showing Mixer, Aerators and Decant Mechanism**

**Operational Data**

On completion of the construction a 90-day study was undertaken with the plant operated using only one half of the SBR capacity because of the then prevalent low influent flow. The other SBR tank was only used as an equalization tank to store untreated wastewater temporarily whilst the SBR was in the non-filling phases. The plant was therefore capable of treating up to 50% of its hydraulic and organic design loads. During this period the plant received an average of 36% of its 1.5 ML/d (0.4 MGD) hydraulic design flow, but since only half of the plant was operated it actually treated the equivalent of an average of 72% of the design flow.

| **Parameter** | **Nov** | **Dec** | **Jan** | **Design** |
|---|---|---|---|---|
| Average, ML/d (MGD) | 0.50 (0.13) | 0.57 (0.15) | 0.55 (0.15) | 1.50 (0.40) |
| Minimum, ML/d (MGD) | 0.42 (0.11) | 0.33 (0.09) | 0.45 (0.12) | - |
| Maximum, ML/d (MGD) | 0.81 (0.21) | 1.02 (0.27) | 0.66 (0.17) | 3.00 (0.80) |
| Total, ML/month (MGD/month) | 14.85 (3.92) | 17.57 (4.64) | 17.01 (4.49) | - |

**Table 2: Influent Flows**

The plant received 39% of its design influent BOD and therefore effectively treated an average 78% of the single SBR basin's design load. Average plant loads are summarized in Table 2, and as expected the loads increased with the seasonal influx of tourists.

| **Parameter** | **Nov** | **Dec** | **Jan** | **Design** |
|---|---|---|---|---|
| $BOD_5$, kg/d (%) | 110 (31.9) | 140 (40.6) | 156 (45.2) | 345 |
| TSS, kg/d (%) | 84 (37.3) | 104 (46.2) | 113 (50.2) | 225 |
| TKN, kg/d (%) | 23 (29.5) | 26 (33.3) | 30 (38.5) | 78 |
| TP, kg/d (%) | 3.8 (25.3) | 4.4 (29.3) | 5.1 (34.0) | 15 |

**Table 3: Influent Loadings**

***Note:*** The % relates to design load which should be doubled to compensate for only 1 SBR in operation.

Daily measurements of key influent and effluent parameters were performed during the entire evaluation period. Samples were analyzed in accordance with the site's permit requirements. The results show the plant was 100% compliant with respect to all effluent quality parameters during the course of the evaluation.

BOD removal is exactly in line with expectations of a well designed and operated AS system and would be basically the same whether an MBR or TMF system had been employed. The Turbidity and Suspended Solids removal is of course higher than for a conventional AS system and is similar to an MBR system.

| **Parameter** | **Min** | | **50-percentile** | | **90-percentile** | | **Max** | |
|---|---|---|---|---|---|---|---|---|
| | **Value** | **Limit** | **Value** | **Limit** | **Value** | **Limit** | **Value** | **Limit** |
| $BOD_5$, mg/l | | | 1 | 2 | 1 | 4 | 2.1 | 10 |
| TSS, mg/l | | | 0.2 | 4 | 0.2 | 5 | 1 | 10 |
| $NH_3$-N, mg/l | | | 0.1 | 0.7 | 0.3 | 0.8 | 0.5 | 1.0 |
| TN, mg/l N | | | 4.2 | 7 | 6.4 | 10 | 6.9 | 15 |
| TP, mg/l P | | | 1.0 | 1 | 2.2 | 3 | 3.8 | 5 |
| *E. coli*, org/100 ml | | | | | | | 0 | 10 |
| O&G, mg/l | | | 1 | 2 | 2 | 5 | 4 | 10 |
| Turbidity, NTU | | | 0.12 | | 0.18 | | 0.37 | |
| pH, std. units | 6.7 | 6.5 | | | | | 8.0 | 8.5 |

**Table 4: Effluent Quality *vs.* Permit Requirements**

***Notes:***

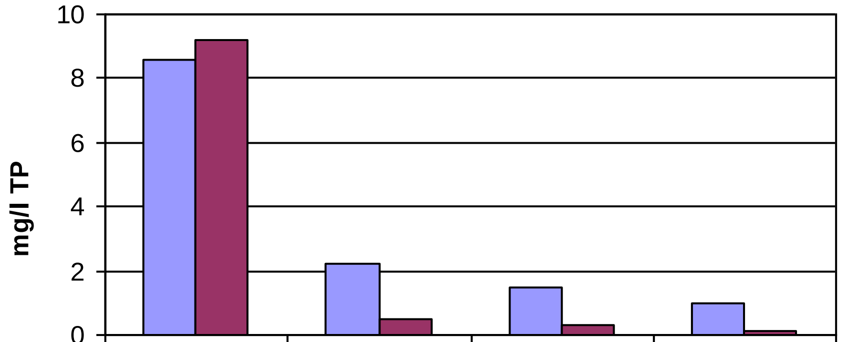
1. The laboratory limit of detection (LOD) for $BOD_5$ was 2 mg/l. Where $BOD_5$ is reported as 1 mg/l, the lab results were simply given as <2 mg/l.
2. The laboratory LOD for TSS was 3 mg/l. Since all final effluent levels were <3 mg/l, TSS values were estimated by multiplying the NTU turbidities by a factor of 2.
3. Whereas the laboratory reported the *E.coli* populations as <1 organism/100 ml, they appear here as 0 organisms/100 ml.
4. The laboratory LOD for oils and greases (O & G) was 2 mg/l. Where O & G is reported as 1 mg/l, the lab results were simply given as <2 mg/l.

**Phosphorus Removal**

During the study, there was no need to dose extra alum upstream of the cloth media filter since the total phosphorus (TP) limit was achieved by injecting the chemical into the influent equalization tank and the SBR tank during the react phase. With a total alum dose of 70 mg/l (as 48% alum solution), the SBR effluent typically contained 2 to 3 mg P/l. At least 50% of the Total P was estimated to have been eliminated biologically based on alum use. The cloth media filter provided an additional 50% reduction of the remaining particle-associated phosphorus.

To demonstrate the ability to achieve very low TP values, the MBTP was tested, by injecting alum into the flocculation tank, over a 40-day period following the initial 90-day process evaluation. The objective was to determine the dosing required that achieved a final 0.1 mg/l TP value while meeting all other effluent quality limits. A 21 mg/l alum dose in addition to about

70 to 83 mg/l into the SBR consistently achieved the 0.1 mg/l target.  It should be noted that these dosages are expressed as the 48% bulk product rather than as 100% alum.




| | Influent | SBR Effluent | Cloth Media Filter Effluent | Membranes Effluent |
|---|---|---|---|---|
| 1.0 mgTP/l target | 8.6 | 2.2 | 1.5 | 1 |
| 0.1 mgTP/l target | 9.2 | 0.5 | 0.3 | 0.1 |

**Figure 6: Reduction of Phosphorous at various points in the MBTP.**

Again, as with the BOD, turbidity and Suspended Solids reduction, the Multi-barrier method using tertiary membrane filtration was demonstrated to be at least as effective as an MBR for removing Phosphorous.

**Economics**

The breakdown of operating cost is illustrated in Figure 7. The cost basis is calculated using a 7% rate of return on a 20-year period based on the design flow, resulting in an amortized annual cost of $80,042.  This summary excludes all capital and installation costs.

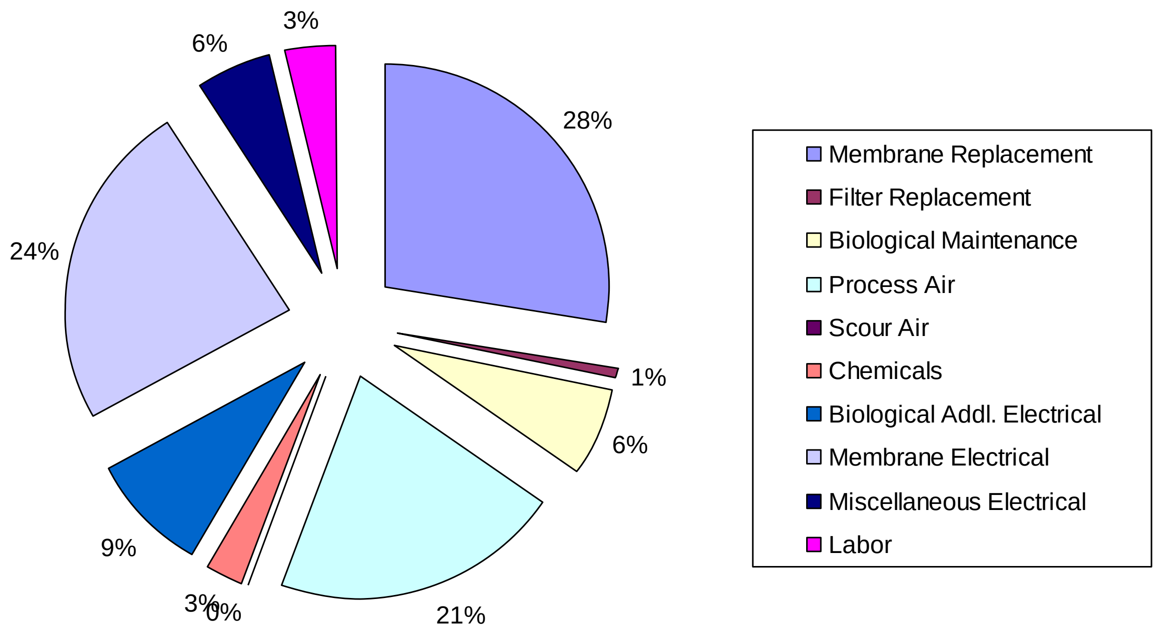



**Figure 7: MBTP Operational Cost Distribution.**

The operating costs for a similar sized MBR system are somewhat higher due mainly to the impact of membrane replacement costs. As can be seen in Figure 7, the membrane replacement costs are the largest single item in the operations budget. The MBR requires at least double the membrane area and given similar prices per unit membrane area it is clear that this has a large impact on the operating cost comparison. Furthermore it is not unreasonable to expect a longer membrane lifetime for the Tertiary Membranes than for the MBR membranes given the much heavier duty that the MBR membranes endure.

The power requirements for the tertiary membrane system (24% of the total costs) are mainly associated with pumping the feed and backwash water. In an MBR typically the power costs are a little over one third of the total operating costs. Approximately 34% of the total power is used for MBR membrane air scour (typically course bubble aeration), and about 42% for the process air (fine bubble aeration). The remaining 24% of power is used for pumping and mixing of which only 4% is related to the permeate pumps. Even though the division of the power use is different for the two technologies the overall power consumption is reasonably similar, and in the order of 1 to 2 kWhr/cubic meter of water treated.

## Conclusions

When evaluating a membrane treatment scheme it is recommended that the engineer considers both MBR and TMF as both are capable of producing similar high quality final effluent water in a reliable manner. In general if land area is limited or expensive the MBR is likely to be the favored option. If an existing facility requires an upgrade for extra flow the MBR is also a very good candidate.

However when land is not a major constraint it quite likely that the TMF systems will offer better economics largely due to the significantly lower membrane areas required. Furthermore the TMF systems offer process flexibility that cannot be achieved with an MBR for example additional dosing points to achieve higher phosphorous removal and the ability to deliver water of progressively higher quality from each of the consecutive unit processes. This could be especially attractive if for example a portion of the wastewater is to be treated to a very high standard for a reuse application and the remainder is discharged into a river or the sea.

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**About the Author**

Dr. Nicholas Powell is an independent consultant with over 20 years experience in the field of membranes especially in the water and wastewater industry. He specializes in strategy and business development and can be contacted at nick@membraneconsultant.com