Introduction to membranes: An introduction to membrane bioreactors

Continuing his series of articles looking at membrane filtration technology, Graeme Pearce takes a look at membrane bioreactors, a rapidly growing sector of the filtration industry.

Background

This article is the tenth in a series describing membrane filtration technology used for water and wastewater treatment. The previous articles have provided an introduction to the field and examined the basics of membranes, modules, process design, and operation in water and wastewater applications. The series then looked at a comparison of manufacturers' products for UF and MF, and is now being concluded with a review of MBR technology and products in the final three articles.

Membrane Bioreactors (MBRs) were first developed 40 years ago and have been used commercially in Japan for almost 30 years. Since 1990, MBR technology has been taken up in North America and Europe, and is now experiencing rapid growth in a wide variety of applications. In this article, an introduction will be provided for the use of membrane bioreactors in wastewater treatment. The next article will provide an overview of MBR suppliers, with a detailed review of the leading companies' products given in the final article.

MBRs for wastewater treatment

MBRs are used to treat biologically active wastewater feeds from municipal or industrial sources. The MBR process competes with biological treatment such as the Conventional Activated Sludge (CAS) process used in municipal wastewater treatment applications. In addition to CAS, industrial wastewaters can be treated with Rotating Biological Contactors (RBC) and Sequencing Batch Reactors (SBR), depending on application requirements. Conventional biological processes perform well in meeting normal discharge standards, and are cost effective. However, they can struggle to meet treatment standards for discharge into sensitive environments. In addition, conventional processes are not normally cost effective for reuse, unless UF or MF membranes are used as a post treatment. This simple upgrade can be the most significant competitor to the implementation of MBR. Drivers for the use of membranes in wastewater treatment are summarised in Table 1.

Membranes are used in wastewater applications in which a higher treatment standard is required than that achieved by conventional processes. Membranes can be used for filtration, i.e. ultrafiltration (UF) and microfiltration (MF), and for the removal of dissolved substances, such as salts and dissolved organics using reverse osmosis (RO) and nanofiltration (NF). Membrane filtration is often used to provide pre-treatment for RO and NF, but the filtration stage itself can be the treatment goal.

Wastewater treatment encompasses a broad range of applications in both municipal

Table 1: Market drivers for membranes in wastewater
Discharge
• Easily meets regulatory levels for discharge standards
• Used for discharge to pristine environments
Reuse
• Essentially mandatory for meeting standards in potable applications
• Membrane filtration pre-treatment mandatory prior to RO/NF
• Increased value for industrial applications
• May be instrumental in obtaining development permit

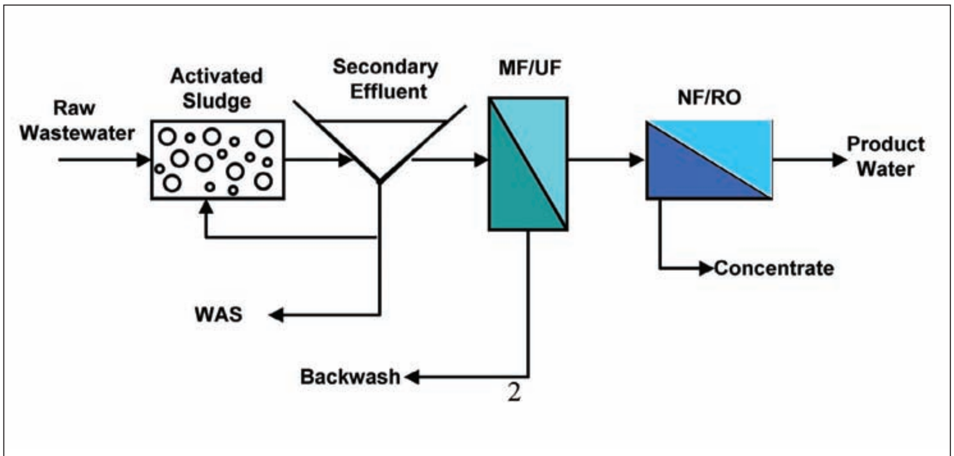

Figure 1: Conventional Activated Sludge (CAS) – MF Tertiary Membrane Systems.

and industrial sectors. This article discusses membrane processes to provide an effluent for discharge, or feedstock for a reuse process, and will focus on membranes used within MBRs. Since membrane filtration increases the cost of wastewater treatment, MBRs are mainly used where significant value is added to the wastewater stream.

The treatment stages for wastewater processes are defined in Table 2. Note that both types of membrane process, ie filtration and the removal of dissolved substances, are defined as quaternary processes or advanced treatment. Membrane filtration and MBR processes tend to cut across these definitions by potentially combining several stages in one unit operation.

Table 2: Wastewater Treatment Stages
Primary
• Screening, grit removal, pre-aeration, flow equalisation
Secondary
• Biological oxidation, e.g. Conventional Activated Sludge (CAS)
Tertiary
• Physical, chemical, or biological treatment to improve 2ry quality e.g. coagulation, sand filtration
Quaternary (or Advanced Treatment)
• Additional stage of treatment e.g. membrane processes, including membrane filtration (UF/MF) and RO/NF for TDS/organics

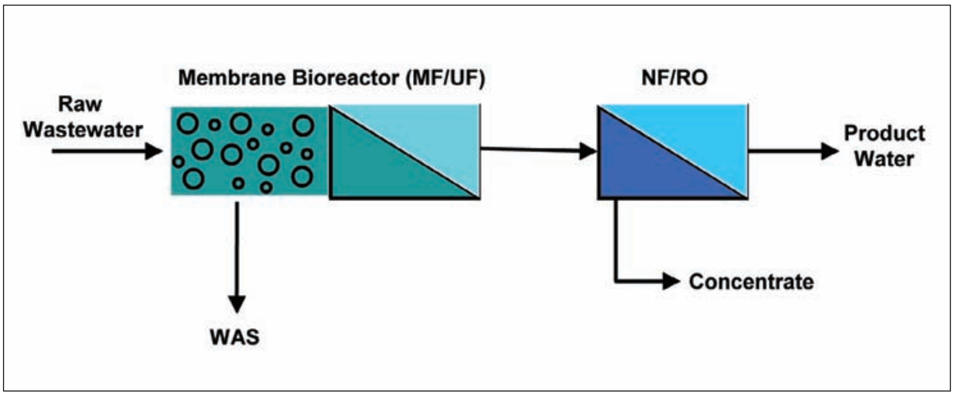

Figure 2: Membrane bioreactor (MBR) process.

The membrane bioreactor process

Figure 1 shows the conventional activated sludge (CAS) process followed by membrane treatment. CAS produces a secondary effluent which can be easily treated by an outside feed format UF/MF system. If a sand filter is used after the CAS, a tertiary effluent is formed which can be treated by either inside or outside feed formats.

In wastewater reuse applications, a significant proportion of projects only require rudimentary treatment, i.e. secondary or tertiary stages. For projects requiring quaternary treatment, UV or ozone would provide disinfection, but normally a particle and pathogen barrier is required, in which case, the only option is to use membrane filtration for polishing. Application requirements therefore define whether membranes are needed. If dissolved substances need to be removed by RO, membrane filtration is essentially mandatory as a pre-treatment to RO in order to achieve stable performance.

Membrane bioreactors (MBR) provide an alternative to CAS-UF/MF by combining biological oxidation with the UF/MF membrane separation in one unit operation, though this is still normally a two tank process. Figure 2 shows a process flow drawing of the MBR, illustrating its simplicity. Some MBR technology uses the same membranes and even the same membrane devices as those used for polishing technology. In other cases, membranes and module formats have been developed specially for MBR requirements. The next article will explore the different membrane and format options of MBR technology.

Advantages of MBR

The concept of MBR was first developed to exploit the fact that the biological wastewater treatment process and the process of membrane fouling control can both use aeration. However, bio-treatment utilises fine air bubbles, since oxygen needs to be absorbed for the biological reaction step. In contrast, fouling control is best achieved by larger bubbles, since the air is required to scour the membrane surface or shake the membrane to remove the foulant. In addition, other aeration requirements for the two processes are not matched (e.g. volume and the location of where the air is applied), thus the potential for dual purpose aeration is strictly limited. In consequence, the MBR process uses more air, and hence higher energy than conventional treatment. The other advantages of MBR therefore need to outweigh this disadvantage to be considered.

The main advantage of the MBR process is that it reduces the importance for biomass sedimentation, thus allowing a significantly smaller tank to be used for the bio-treatment process. Biosolids are low in density and hence settle relatively slowly, and therefore a conventional biological process requires a large tank to ensure good removal. In contrast, MBRs provide a barrier for particulates, and hence carryover of solids from the bio-treatment tank can be tolerated to some extent, though attention needs to be paid to fouling control.

Concentration of the bio-solids can increase the efficiency of the bio-treatment process [1] thereby improving the removal of dissolved constituents, and reducing sludge production. Also hydraulic retention time (a function of flow rate) can be de-coupled from sludge retention time (a function of biological reaction processes and sludge setting rates), providing more flexibility in coping with flow rate and feed quality variation than with a conventional treatment process. Figure 3 shows a comparison of footprint from various wastewater treatment processes [2].

The second main advantage of an MBR is that the treated water quality is better than from a conventional process, since the membrane barrier removes essentially all particulates above the pore size rating of the membrane. In addition, MBR provides excellent pre-treatment for subsequent RO or NF stages, as discussed in article 6 of this series.

Comparative energy usage

Metcalfe and Eddy carried out a survey of conventional wastewater treatment facilities in the US [3], and found that the energy usage range was 0.32 – 0.66 $kWhr/m^3$. Energy usage in wastewater treatment is somewhat lower in Europe according to Black and Veatch [4], who have carried out extensive surveys of wastewater treatment costs. This is partly due to a greater consciousness for energy efficiency, and partly due to the fact that average BOD loading/capita in the US is 20-25% greater than Europe (due to the use of kitchen disposal units). Long term monitoring of wastewater treatment systems has shown usages as low as 0.15 $kWhr/m^3$ for activated sludge, increasing to 0.25 $kWhr/m^3$ if a biological aerated filter (BAF) stage is included.

Membrane filtration after conventional treatment is estimated to add 0.1 – 0.2 $kWhr/m^3$

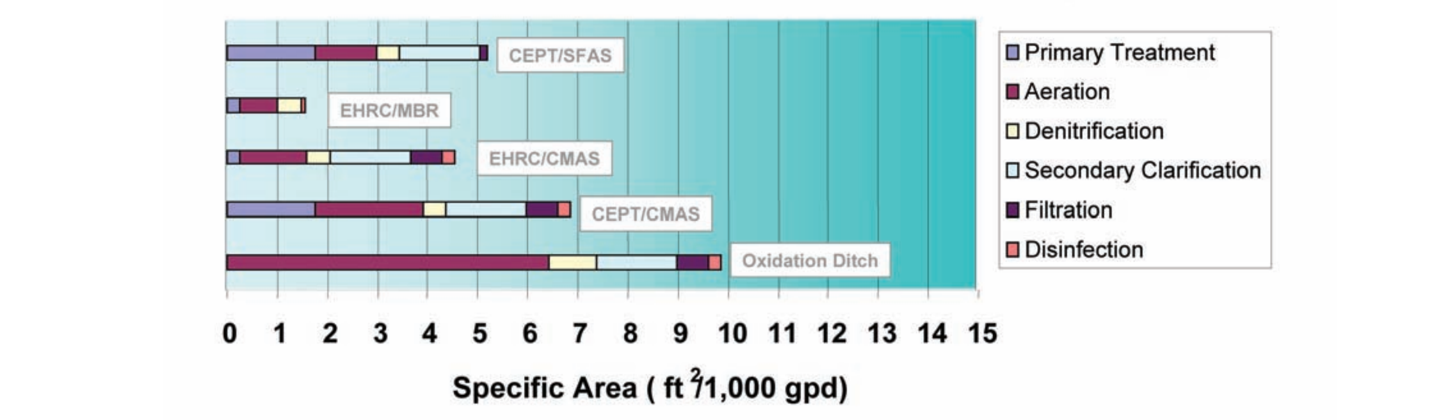

Figure 3: Footprint example – MBR vs alternate technologies. (NB. 1 ft^2/1000 gpd ≡ 0.0246 m^2/mld (or 1000 m^3/d))

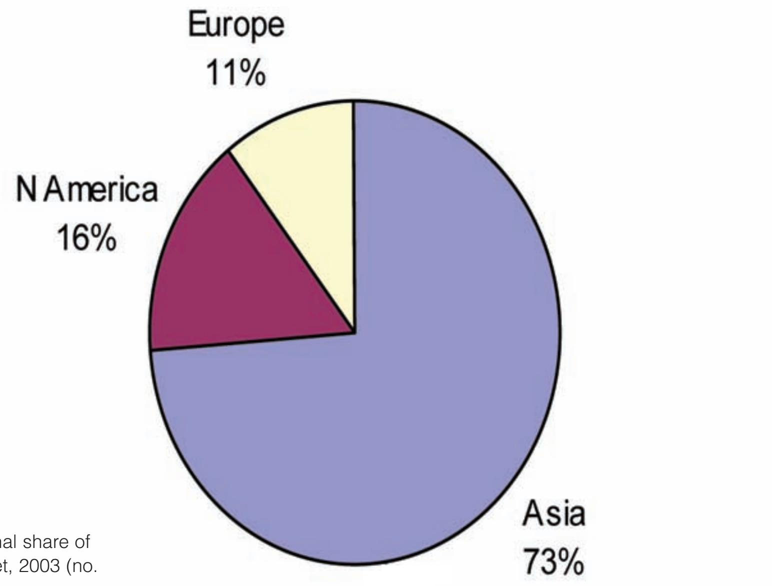

Figure 4: Regional share of total MBR market, 2003 (no. of plants).

to the energy, equivalent to a total energy use for CAS-UF/MF of 0.35 – 0.5 kWhr/m^3 in a new facility.

MBR provides an equivalent treatment level to CAS-UF/MF, but at the expense of higher energy cost since the efficiency of air usage in MBR is relatively low. Experience of large scale commercial MBRs shows an energy usage of around 1.0 kWhr/m^3, though smaller scale facilities typically operate at 1.2 – 1.5 kWhr/m^3 or higher [1]. However, improvements in air efficiency and membrane packing density are expected to improve these values in the future. Even so, it looks likely that MBR energy costs will continue to exceed CAS-UF/MF by 0.4 kWhr/m^3 or more.

Table 3: Wastewater reuse market segmentation by end user category	
Industry & power	65.5%
Municipal	11%
Agriculture	23%
Other	0.5%

Wastewater treatment cost

The equipment and energy cost of MBR are higher than conventional treatment, but total water costs can be competitive due to the lower footprint and installation costs. MBR costs have declined sharply since the early 1990's, falling typically by a factor of 10 in fifteen years. As MBR technology has become accepted, and the scale of installations has increased, there has been a steady downward trend in membrane prices, which is still continuing. This is particularly notable with the acceptance of the MBRs in the municipal sector. The uptake of membrane technology for municipal applications has had the affect of downward pressure on price, just as in previous generations RO and UF/MF prices have experienced a similar trend.

Evaluation of total water cost shows the competitive position of MBR compared to CAS-UF/MF is sensitive to design and site specific factors. For example, a cost comparison by the US consultant HDR in 2007 showed that MBR was 15% more expensive on a 15 mld case study [5], whereas a study by Zenon in 2003 [6], gave MBR 5% lower costs. The differences were due to the design fluxes assumed and the capital charge rate for the project. Neither study allocated a cost advantage from the reduced footprint, which could typically translate to a treated water cost saving of up to 5%.

MBR markets and applications

Historically, the market for MBRs has been dominated by activity in Asia. This started in Japan in the 1980's, and was followed by an enthusiastic uptake in South Korea in the 1990's, and more recently by China. In 2003, the share by number of plants between major Worldwide markets is shown in Figure 4 [7].

Wastewater treatment applications are found in a broad range of industries. In some cases the driver for treatment is to meet discharge consents; in other cases, it is to provide a resource for reuse. For wastewater feeds that are easy to treat, such as from the Municipal sector, conventional treatment is likely to be sufficient to meet discharge standards, except in particularly environmentally sensitive areas. Most membranes applications in the Municipal sector are in reuse applications.

For industrial wastewater feeds that are difficult to treat, such as landfill leachate, it is quite common to use membranes simply to meet discharge standards. Most industrial wastewaters other than landfill leachate fall between these two extremes, with the end use either for discharge or for reuse, though more commonly the latter. The membrane technology used in any of these applications described above could be UF/MF after conventional treatment, or an MBR.

MBR's tend to be applied either in more difficult applications within the industrial wastewater treatment sector, or to those applications where reuse is the target. The leachate and marine sectors are examples of areas where MBR's are relatively well used. Figure 10 provides a breakdown of the EU industrial market by application in terms of numbers of installations [8].

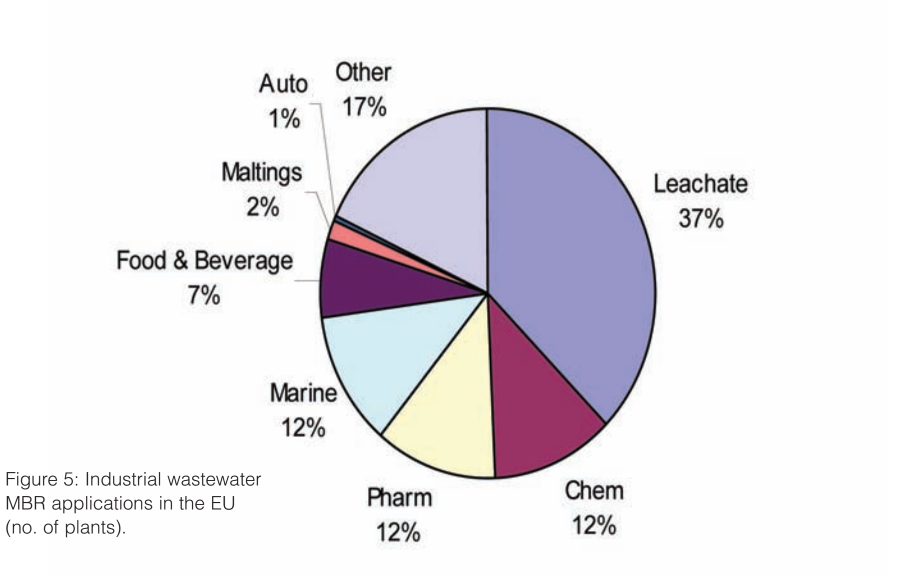

Figure 5: Industrial wastewater MBR applications in the EU (no. of plants).

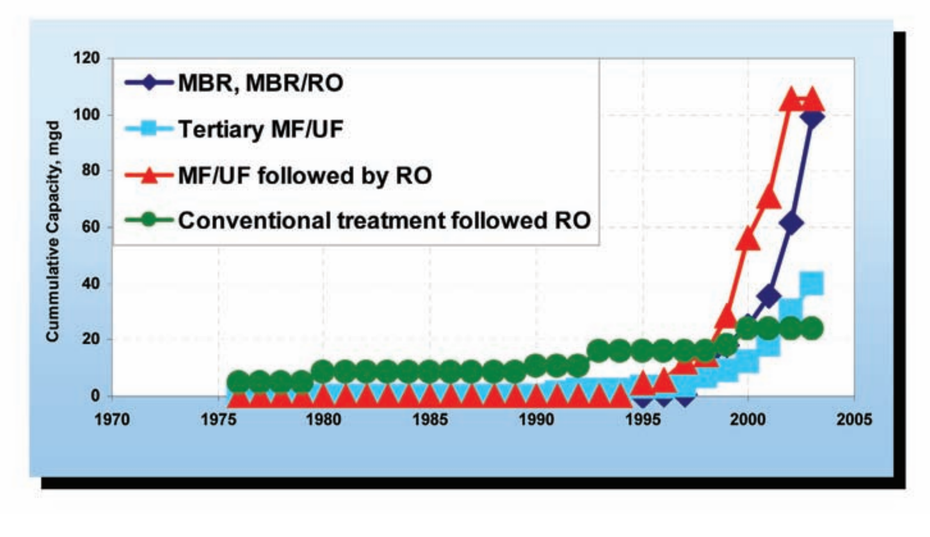

Figure 6: Number and types of membranes used for reclamation.

The applications for which membranes have been preferred to conventional treatment can be summarised as follows:

- Surface water discharge (special circumstances) (MBRs);
- Urban reuse (opportunity for MBRs, MF, UF);
- Groundwater recharge (UF or MF/RO);
- Industrial reuse (MBR/RO from industrial source, UF or MF/RO from municipal);
- Irrigation (if RO needed for reducing TDS).

To be considered for re-introduction to the drinking water supply chain, wastewater normally requires a further level of treatment, i.e. a quaternary stage, e.g. by RO/NF, to provide a barrier for organics. For industrial use, the further treatment might be RO, ion exchange or Electro Dialysis (EDI), since the removal of dissolved inorganics may add significant value, for example in producing boiler feedwater. Table 3 shows the segmentation of the wastewater reuse market by end user [9].

Review of wastewater reuse plants

Figure 6 shows the type of membrane process used in the 120 reuse plants discussed in the WERF report published in 2005 [10].

The survey shows that about 25% of plants included RO, and just over half of plants were MBRs. The RO plants mainly had membrane pre-treatment. The more recent plants show a higher prevalence of RO, since the reclaimed water may be considered for re-entry to the water supply, and for membrane pre-treatment. The MBR tends to be favoured for smaller plants. Highest growth rates are being experienced in areas of greatest water stress for reuse applications, such as the south western US, China, Singapore, and Australia. The low footprint of MBR is a significant driver for developed economies.

Conclusions

MBRs are well established, particularly in Japan where they have been used commercially for almost 30 years.

The MBR has a simple process flow configuration, and is attractive for the following types of application:

- feeds which are difficult to treat;
- high treated water quality requirements, e.g. reuse, pre RO;
- sites where there are footprint constraints.

Current MBR energy requirements are higher than conventional processes even if followed by membrane filtration, though gradual improvements are being made

MBRs are now being implemented for municipal applications, with significant growth rates in parts of North America and other water stressed areas, and growth potential predicted in European markets ●

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