TREATMENT OF INDUSTRIAL WASTEWATER BY MEMBRANE BIOREACTORS

Chettiyappan Visvanathan
Environmental Engineering and Management Program, School of Environment, Resources and Development,

Keywords: Membrane Bioreactor (MBR), Industrial Wastewater, Treatment, Membrane Technology, Research

Contents

Summary

Membrane Bioreactors (MBRs) have attracted a significant attention of scientists and engineers in the past two decades. Improvement of membrane technologies coupled with experiences gained from application of membranes in different industrial processes have opened a gamut of opportunities in industrial wastewater treatment. The solid-liquid separation that is conventionally carried out in gravity-based clarifier is replaced by membrane filtration in a MBR system thus combining the strength of biological treatment processes and efficiency of membrane filtration. This and several other advantages have made the MBR system ideally suited for treatment of strong industrial wastewater and reclamation of water. By late 1990s many commercial application of MBR can be noted in industries and each year this number is increasing rapidly. Researches on MBRs are increasingly funded by municipal councils, industries, membrane and packaged wastewater treatment plant manufacturers, which is a clear sign of popularity and potential of MBR.

In this chapter, an attempt has been made to explain MBR systems and their advantages and drawbacks over conventional biological treatment systems. The implications of such advantages on the design and operation of MBR are discussed. A number of case studies from commercial applications and researches have been put forward to demonstrate the forte, robustness and flexibility of MBR systems in treating different types of industrial wastewater. This is expected to give the reader a good understanding of MBR system, which is considered as one of the best available technologies in the field of wastewater treatment.

1. Introduction

Researches on Membrane Bioreactor (MBR) date back to as early as 1960s. However, commercial use of membrane in wastewater treatment remained limited primarily due to low membrane flux, low permeability, limited membrane life and high cost of membrane. From early 90's due to active researches in the field of membrane technology, a new generation of membranes evolved that dramatically overcame many of the above limitations and the cost of membranes started to decline. This attracted a lot of attention to commercial use of membranes in wastewater treatment. By then use of membranes in other fields of industrial applications including water treatment was common and lot of experiences already gained.

During the same time due to increased environmental awareness, effluent discharge legislations were tightened in several countries. Limitations of conventional biological processes in treating industrial wastewater to meet the discharge standards became more apparent. This led to significant number of researches being directed to alternative technologies and improvement of existing technologies. Consequently, researches on MBR picked up and many of these were actively supported by industries. Initially, many researches were focused on treating domestic/municipal wastewater using MBR. Later and more recently, the possibility of using MBR in different types of industrial wastewater treatment has gained much attention.

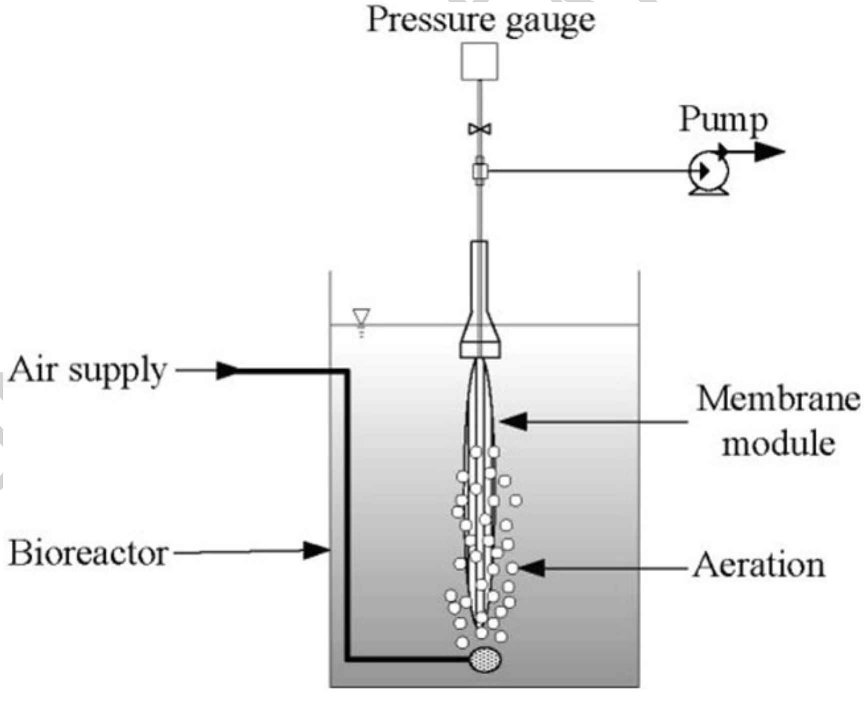

Figure 1 Schematic Arrangement of a typical Membrane Bioreactor

MBR is a major attempt to increase the efficiency of conventional biological wastewater treatment processes by replacing the gravity-based clarifier (used to separate the active biomass from the mixed liquor) by a membrane-aided pressure filtration process. The underlying principle of removal of pollutants by biochemical reaction however remains same in a MBR as in conventional systems. The schematic arrangement of a typical wastewater treatment train using MBR is given below, Figure 1.

As a result of replacing the secondary clarifier by a pressure based membrane filtration process several improvements can be achieved like:

- The performance of solid-liquid separation efficiency is improved due to higher efficiency of membrane filtration over gravity separation;
- The sensitiveness of the separation process to the internal and external factors can be reduced thereby improving the reliability of the system;
- Control on several process related factors can be improved like sludge retention time (SRT) or mean cell residence time, organic loading, waste sludge volume and characteristics etc. that can improve the efficiency of the biochemical reaction process;
- Removal of nutrients and refractory (biodegradation-resistant) substances can be improved;
- Complete removal of microorganisms and pathogens from effluent is possible that reduces the disinfection requirement;
- Less operation control during steady state condition as well as rapid initial process startup can be achieved;
- The footprint of a traditional wastewater treatment plant can be reduced by replacing large (clarifier) tanks with compact membrane modules;
- Better effluent quality from MBR easily lends itself to opportunities of reclamation and recycling of wastewater.

Each of these improvements justifies the use of MBR in industrial wastewater treatment. While the characteristics of raw domestic sewage are predictable, characteristics of industrial wastewater vary widely and are often many times stronger. In addition, intermittent and shock loading, unstable pH, high temperature, turbidity, color, presence of toxic and refractory substances is common with industrial wastewater. As a result, industrial wastewaters are much more difficult to treat and in many cases, large elaborate treatment systems are required. Yet even with such systems, effluent quality (meeting discharge standards) is not guaranteed. Therefore, MBR systems with higher efficiency offer a better solution to industries.

Performance of gravity-based clarifiers is poised on the small difference in the specific gravity of the flocculated biomass and the mixed liquor. As a result, these clarifiers are highly sensitive to a number of internal and external factors, for example pH, temperature, SRT, solid loading etc which need strict operational control. This increases the cost of operation and maintenance and decreases the reliability of the system.

On the other hand, membrane separation, which uses pressure filtration across a selective membrane is a more reliable system and has been widely used in different fields of engineering. Moreover, membranes can be tailored to suit particular application conditions (e.g. higher temperature or turbidity) and performance can be stabilized even when substantial variations of such conditions take place. This makes the MBR system reliable and robust that is needed for industrial applications.

Better control on process related factors can be achieved during both design and operational phases that improves the overall efficiency of the system. This will be discussed in detail later. Operational control gives more opportunity to the operator to tune the process according to the demand (like intermittent or shock loading, variation of pH, temperature, increase in turbidity etc.).

MBRs have shown better performance concerning nutrient removal. Higher SRT or mean cell residence time in the reactor promotes growth of slow-growing nitrifiers (nitrosomonas and nitrobacter) that remove nutrient from wastewater. Higher SRT provides more time to acclimatize and grow specifically cultured microorganisms, which are required to treat refractory pollutants. Such is usually not possible in conventional systems (using gravity-based clarifiers) as longer sludge age may give rise to rising sludge problems.

Membranes can be selected for a wide range of solid separation that can remove all types of bacteria and viruses. Therefore, pathogens can be completely retained and downstream disinfection requirements are reduced. This reduces the cost of plant construction, operation and maintenance.

As design and operation of MBR is more predictable, it lends to more opportunities of automation to avoid frequent manual intervention and observation. During steady state conditions, MBR can practically operate on complete automation.

Due to highly efficient separation efficiency, the time and seeding requirements of a typical MBR is much less during the initial and startup after shutdowns. This is quite important for industries as delay in startup of the treatment system may hold up production.

Industries are sometimes located in areas where land is at premium. In these cases compact systems are desirable for lowering the capital expenditure. Replacing large clarifiers with compact membrane modules saves space that leads to further saving in structure and overall construction cost. Future expansion of the treatment plant is comparatively easier with MBR than conventional systems due to the same reason.

Overall improvement of the treatment efficiency due to MBR leads to better reclamation and recycling opportunity for industrial wastewater. Often, high water demand, water shortage and high cost of water are perpetual issues with many industries. Moreover, in many countries new legislation requires the industry to recycle a major part of its water. Better effluent quality from MBR requires less downstream treatment of the effluent to make it reusable. In industrial context, this is of major significance in terms of waste management and legal requirements making it a prime reason for use of MBR in industrial wastewater treatment.

2. Design of MBR System

Design of an efficient MBR system pivots on the design of a suitable membrane system. In addition, the effect of changes in the (biochemical) process parameters (like organic and hydraulic loading, sludge age, sludge recycling etc) due to change in the solid-liquid separation system need to be considered in the reactor design and other unit processes. The effect of these factors on the design of a MBR is discussed in the next sections.

2.1 Membrane System Design

Today, there are different variants to MBR system in commercial use including proprietary types. MBR is developed both for suspended growth and attached growth processes. With more researches and several membrane manufacturers competing for the market, more variants are evolving. The two most common types are discussed below.

Submerged MBR (sMBR) is by far the most common type of MBR in which the membrane modules are directly installed in the activated sludge reactor vessel, Figure 2. The permeate or effluent is sucked out of the membrane module with the help of a permeate pump and the suspended solids fall back into the basin. Sludge wasting is done directly from the reactor. sMBRs are very popular because of their compactness and low energy requirement. However, sMBRs need more membrane area and are more suitable for wastewater with good filterability.

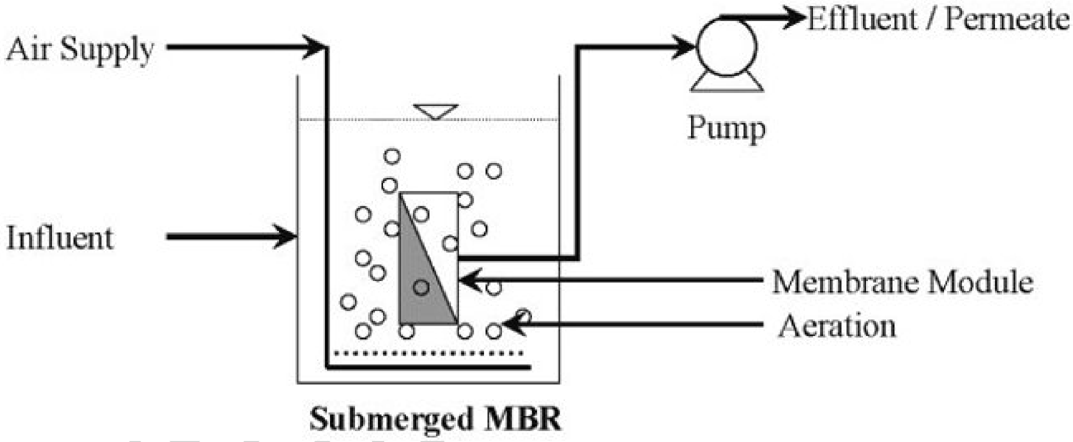

Figure 2 Submerged MBR for Suspended Growth Process

In External Membrane (also called Cross flow or Sidestream) MBR, the membrane modules are located outside the reactor basin, Figure 3. In this system, the mixed liquor from the reactor is pumped into the external membrane module. External MBRs are also commercially used in industries as these require less membrane area compared to submerged MBRs and work better for high strength wastewater with poor filterability. However, these MBRs consume more energy and need additional space and manifolds.

Choice of a particular system configuration depends upon the application requirement and there is no clear-cut rule for selection. Designers should use engineering judgment to choose a particular configuration after considering all the factors related to the application. Table 1 shows the key differences between the Submerged and External Membrane Bioreactors that should be considered in adopting a configuration.

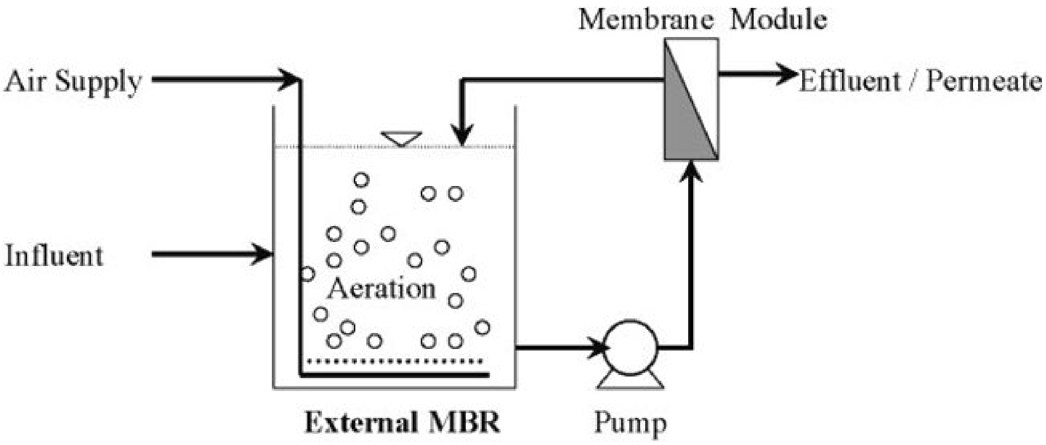

Figure 3 External Membrane Bioreactors for Suspended Growth Process

	Submerged MBR	**External MBR**
Suitability	Low strength wastewater with good filterability	High strength wastewater with poor filterability
Membrane Flux	Lower membrane flux or lower permeate per unit area of membrane	Higher membrane flux or higher permeate per unit area of membrane
Transmembrane pressure	Lower TMP is required	Higher TMP is required
Power Requirement	Less power is required per m^3 of wastewater treated	More power is required per m^3 of wastewater treated
Sensitivity	Less sensitive to variations in wastewater characteristics and flow fluctuations	More sensitive to variations in wastewater characteristics and flow fluctuations
Membrane area requirement	More area is required	Less area is required
Economics	Generally less expensive at lower wastewater influent rate	Generally more expensive at lower wastewater influent rate
Membrane Backwashing & Cleaning	More frequent backwashing and cleaning required	Less frequent backwashing and cleaning required
Operation	Less operational flexibility	More operational flexibility with control parameters like SRT, HRT and MLVSS
Extension of WWTP Capacity	Difficult to extend	Easier to extend

Table 1 Comparison of Submerged and External MBR Systems

Different membrane configuration can be used in MBRs. Hollow fibre and tubular membranes are commonly used in MBRs. These are operated in cross flow mode. Flat sheet membranes are also used for commercial MBR systems. When submerged hollow fibre or tubular membranes are used, the permeate is obtained by means of a dead-end filtration. Membranes are usually assembled in compact modules containing several units of individual membrane units. In packing the membranes within the module, care should be taken that the membranes are not packed too densely that may hinder the mixed liquor circulation along the surface of the membranes vis-à-vis render higher dead volume zones of low flow circulations (Case Study 1). For submerged MBRs, several modules are installed in rows in the reactor vessel. The modules can be oriented vertically or horizontally and are supported by frames and other holding devices.

The effect of fibre diameter and packing density on the fouling performance of MBR was studied with semi industrial pilot scale MBR. Hollow fibre membranes (diameter of 1.4 mm and 2.4 mm) with dead end filtration were used in the study. Different operating conditions were tested to study fouling in two modules of different packing densities. The results showed that the module with higher fibre diameter and lower packing density developed less dead volume (zones of low flow circulation) compared to the one with lower diameter and higher packing density. These volumes depended on module configuration and were very sensitive to the variation of liquid velocity in a range of low velocities. It could be concluded from the study that more compact bundle would limit the real flow of liquid inside the fibres in the deepness of the bundle, and thus the effective filtration area would be reduced. Fouling was also found to be low for the module with lower packing density.

Source: Pollet et al, 2008

Case Study 1: Effect of Packing Density on Membrane Performance

Predominantly Ultrafiltration (UF) membranes are used for MBRs as these membranes achieve some sort of balance among effluent quality, energy requirement and membrane clogging for treatment of wastewater. Microfiltration membranes allows more solids in the effluent, and Nanofiltration (NF) or Reverse Osmosis (RO) membranes requires much more energy and will be subjected to frequent clogging. However, researches with MBRs using Microfiltration or Nanofiltration membranes have been noted. Microfiltration membranes used in MBRs typically have a pore size of 0.2-0.6 µm and are manufactured from inorganic and organic polymeric compounds.

Membrane life can vary widely depending mainly upon operating conditions, membrane material and configuration, and maintenance. Manufacturers generally provide some guidelines on the usable life of membranes, which should be taken into consideration during design. Generally useful life of submerged membranes is about 5 years while that for external membranes is about 7 years after which, irreversible fouling and physical damages start to deteriorate the membranes permanently.

Membrane area can be determined from the following empirical relationships:

$$\text{Permeability}\ (\text{m}^3/\text{m}^2/\text{h/Pa}) = \frac{\text{Flux}\ (\text{m}^3/\text{m}^2/\text{h})}{\text{TMP (Pa)}}$$

$$\text{Flux (m}^3\text{/m}^2\text{/h)} = \frac{\text{Flow (m}^3\text{/h)}}{\text{Total membrane area (m}^2\text{)}}$$

Transmembrane pressure (Pa) = Inlet Pressure (Pa)-Permeate Pressure (Pa)

Calibrated charts showing the relationship between membrane permeability and transmembrane pressure (TMP) or flux and TMP can be obtained from the manufacturer. However, the charts should be used with care as behavior may differ for actual wastewater due to differences in tested conditions and field conditions. Effect of following factors should also be taken into account:

- Membrane outage during backwashing and membrane cleaning;
- Operational conditions (e.g. shock loading, temperature and pH variation, solid loading etc);
- Dead volumes (unutilized membranes areas due to hindered circulation of feed along the surface of membranes) due to packing density and membrane diameters;
- Progressive deterioration of membrane with age;
- Physical damages.

In absence of any detail calculation, nominal membrane area calculated from manufacturer’s charts should be increased by 60-80% to take into account effect of the above factors.

As can be observed in Figure 4 (modified from Defrance and Jaffrin, 1999), higher flux would require higher TMP and during the initial part flux increase is directly proportional to the TMP (straight line portion). Thereafter, further increase in TMP does not increase the flux proportionally due to pronounced membrane clogging. From practical point of view, design and operation of membranes should be limited to the linear portion of relationship. Generally for sMBRs, flux is obtained in the range of 20-50 L/m^2-h at a operative TMP of 25-60 kPa as compared to 80-130 L/m^2-h at a TMP of about 200 kPa for external membranes, depending on the several factors like mixed liquor characteristics, operating conditions, type of membrane etc. Cross flow, velocities are maintained between 0.3-0.6 m/s.

-
-
-

Bibliography

Badania Z., Ait-Amar H., Si-Salah A., Brik M. and Fuchs W. (2005). Treatment of textile waste water by membrane bioreactor and reuse. *Desalination* 185, 411–417. [A case study on removal of color in textile wastewater by fungus MBR].

Changa J., Changa C., Chena A., Erdeib L. and Vigneswaran S.(2006). Long-Term Operation of Submerged Membrane Bioreactor for the Treatment of High Strength Acrylonitrile-Butadiene-Styrene (ABS) Wastewater: Effect of Hydraulic Retention Time. *Desalination*, 191(1-3), pp. 45-51 (PERIODIQUE).[A case study on treatment of refractory substances by MBRs]

Defrance L. and Jaffrin M.Y. (1999). Comparison between filtrations at fixed transmembrane pressure and fixed permeate flux: application to a membrane bioreactor used for wastewater treatment. *Journal of Membrane Science* 152, 203-210.[This presents the comparison between filtrations at fixed tansmembrane pressure and fixed permeate flux for MBR]

Ferre V., Churchouse S. J., P Judd J. S. and Warren S. (2007). Analysis of Long Term Performance of a Full-Scale MBR Plant Treating Domestic and Industrial Wastewater, 2nd IWA National Young Water Professionals Conference, Berlin, Germany.[A discussion on performance of MBR , membrane fouling, influence of EPS with HRT].

Galil N.I and LevinskyY. (2007). Sustainable reclamation and reuse of industrial wastewater including membrane bioreactor technologies: case studies. Desalination 202, 411–417. [A case study on treatment of paper mill wastewater using MBR].

Gunther Gehlert., Hubert Wienands. and Tony Robinson. (2007). Low-Energy Membrane Bioreactors with External Membranes .WEHRLE Umwelt GmbH, Germany. (Proceedings of Harrogate International Conference, UK), Membranes for water and wastewater treatment, 15 - 17 May 2007. *MBR alternative Confiuirations*, Paper 8a.[A case study on energy consumption of external membrane configuration].

Hai F. I., Yamamoto K., Nakajima F. and Fukushi K. (2007). Textile effluent treatment by fungi MBR with sludge bed /GAC adsorption: Long-term performance of compact hollow-fiber module and overall treatment (Proceedings of the 4th International Water Association Conference on Membranes for Water and Wastewater Treatment, 15-17,May 2007, Harrogate, UK. CD) ISBN number: 978-1-86194-127-5, Paper 39b.[A discussion of membrane cleaning using chlorine based compounds and a case study on color removal from textile wastewater by MBR].

Howell J. A., Chua H. C. and Arnot T. C. (2004). In Situ Manipulation of Critical Flux in a Submerged Membrane Bioreactor Using Variable Aeration Rates, and Effects of Membrane History. *J of Membrane Science*, 242(1-2), 13-19.[This discusses effect of MLSS on membrane fouling].

Igor Ivanovic and TorOve Leiknes. (2007). Impact of aeration rates on particle colloidal fraction in the biofilm membrane bioreactor (BF-MBR). *Membranes for water and wastewater treatment* (Proceedings of Harrogate International Conference, UK,15 - 17 May 2007). MBR alternative Confiuirations, Paper 31b. [A case study on effect of aeration rate on membrane performance].

Paul M. S. (2006) Membrane Bioreactors for Industrial Wastewater Treatment: Applicability and Selection of Optimal System Configuration. Courtesy of WEFTEC 2008, Originally published Oct. 2006, (Water Environment Federation’s Annual Technical Exhibition and Conference -WEFTEC).[This presents the effect on life of submerged membrane and external membrane due to irreversible fouling and physical damages and discusses on trans membrane pressure].

Pollet S., Guigui C. and Cabassud C. (2008). Fouling and Its Reversibility in Relation with Flow Properties and Module Design in Aerated Hollow Fibres Modules for Membrane Bioreactors, *Water Sci Technol* **57**(4), 629-36. [A case study on effect of packing density on membrane performance and discussion on the proactive process, as module design of aerated hollow fibre membrane to reduce membrane fouling].

Ni C.H., Chen C.H., Chen H.C. and Lin Y.C. (2007). Development of MBR Technology in Industrial Wastewater Treatment and Reclamation in Taiwan - with Case Studies. *Membranes for water and wastewater treatment* (Proceedings of Harrogate International Conference, UK , 15 - 17 May 2007).MBR case studies, Paper 10b. [A case study on treatment of electronic and petrochemical industry wastewater by MBR].

Nicolas Lesage., Mathieu Sperandio. and Corinne Cabassud.(2008). Study of a hybrid process: Adsorption on activated carbon/membrane bioreactor for the treatment of an industrial wastewater. *Chemical Engineering and Processing: Process Intensification* **47(**3), 303-307.

[A case study on treatment of mixed sewage from industries by MBR]

Qin J., Wai M., Tao G., Kekre K. A. and Seah H. (2007). Membrane Bioreactor Study for Reclamation of Mixed Sewage Mostly from Industrial Sources. *Separation and Purification Technology* **53** (1)**,** 296–300. [A discussion on hydraulic retention time required for mixed industrial sewage].

Scholz W. and W. Fuchsm W. (2000). Treatment of Oil Contaminated Wastewater in a Membrane Bioreactor. Water Resource 34 (14), pp. 3621-3629. [A case study on removal of hydrocarbons from wastewater by MBR].

Xia Huang, Chun Liu and Hui Wang.(2007). Start-up of a Membrane Bioreactor Bioaugmented with Genetically Engineered Microorganism for Enhanced Treatment of Atrazine Containing Wastewater. *Membranes for water and wastewater treatment* (Proceedings of Harrogate International Conference, UK, 15 - 17 May 2007). MBR Design, Paper 1a. [A case study on treatment of Atrazine using MBRs].

Yang W. and Cicek N. (2007). Treatment of Swine Wastewater by Submerged Membrane Bioreactors with Consideration of Estrogenic Activity Removal. *Membranes for water and wastewater treatment* (Proceedings of Harrogate International Conference, UK, 15 - 17 May 2007). MBR, micropollutant fate and removal, Paper 54a. [A case study on removal of nutrients from wastewater by MBR].

Yoon S., Collins J. H., Davè B. and Koppes J. (2007). Use of Modified Cationic Polymers for the Reduction of Membrane Fouling in Membrane Bioreactor. *Membranes for water and wastewater treatment* (Proceedings of Harrogate International Conference, UK, 15 - 17 May 2007). MBR fouling, Paper 3b. [A case study, reporting effects of biopolymers on membrane fouling].

Biographical Sketch

C. Visvanathan, is Professor of the Environmental Engineering Program, School of Environment, Resources and Development, Asian Institute of Technology. He has a Ph.D. (Chemical/Environmental Engineering) from Institute National Polytechnique, Toulouse, France. His main areas of research interests include: Solid - liquid separation technologies for water and wastewater treatment, waste auditing and cleaner production and solid waste disposal and management. Dr. Visvanathan has published more than 50 international journal and conference papers. His professional experiences include: Project Engineer, Asia Division, International Training Center for Water Resources Management, Sophia Antipolis, France, and short term consultant to UNEP Industry and Environment Office, Paris, France.