

# MEMBRANE TECHNOLOGY FOR ORGANIC REMOVAL IN WASTEWATER

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## Summary

Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) are presented in terms of fundamental theory and applications. The efficiency of MF, UF, NF and RO in terms of removal of organic matter, endocrine disrupting chemicals (EDCs)/pharmaceutical and personal care products (PPCPs) removal (representation of small molecular weight (MW) compounds) and MW distribution (different MW sizes) is reviewed. The factors affecting membrane fouling and the removal of different organics are extensively dealt with in this chapter.

## 1. Introduction

Membrane filtration which is classified into microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) is a pressure driven process in which the

membrane acts as a selective barrier to restrict the passage of pollutants such as organics, nutrients, turbidity, microorganisms, inorganic metal ions and other oxygen depleting pollutants, and allows relatively clear water to pass through. With technological advances and the ever-increasing stringency of water quality criteria, membrane processes are becoming a more attractive solution to the challenge of producing high quality water from wastewater reuse processes. A number of books have been published on membrane technology in a wastewater treatment plants (WWTPs) (Vigneswaran and Ben Aim, 1989; Ho and Sirkar, 1992; Mallevialle et al., 1996; Mulder, 1996; Water Environment Federation, 2006). The books cover a wide range of theoretical mass transport and application on MF, UF, NF and RO. However, to date, not many studies have dealt with detailed removal processes of organic matter, endocrine disrupting chemicals (EDCs) and pharmaceuticals and personal care products (PPCPs). This chapter focuses on achieving detailed organic removal in terms of dissolved organic carbon (DOC), molecular weight distribution (MWD) and EDCs/PPCPs. DOC indicates the general level of pollutant removal by different membranes used. EDCs and PPCPs represent removal of the smallest compounds (approximately 150–500 Da). MW distribution provides information on the removal of the different ranges of MW.

## **2. Overview of Membrane Technology**

Membrane technology has been applied in various fields of wastewater reuse. MF and UF membrane systems have already proven their advantages in terms of economic efficiency as well as water quality. NF and RO membranes are also used in a broad range of wastewater reclamation.

MF refers to membranes that have pore diameters from 0.1 to 10  $\mu\text{m}$  (Cheryan, 1998) and is the membrane with the largest pores. It can be used to filter suspended particulates, large colloids, bacteria and organics. The MF is also used as a pretreatment for NF and RO processes. Since the pore size of the MF is relatively large, air backflush or permeate backwash can be used to remove the deposits from the pores and surface of the membrane. Physical sieving is the major separation or rejection mechanism in MF. The deposit or cake on the membrane also acts as a self-rejecting layer, and thus MF can retain even smaller particles or solutes than its pore size. Membrane bioreactor (MBR) technology is the most promising development in biological WWTPs. The principal element of the MBR is MF. Now, when economic reasons no longer limit the application of MBR in industrial and municipal WWTPs, and new requirements are being set for WWTPs, MBR may be the key for direct or indirect recycling of wastewaters. This is because two of their characteristics, namely: (a) the low sludge load in terms of BOD, so that the bacteria are forced to mineralize poorly degradable organic compounds; and (b) the long life of the sludge gives the bacteria time to adapt to the treatment-resistant substances. The use of membrane separation technologies in water industry is gaining popularity due to increasing environmental regulations, and capability of membrane to remove most of the pollutants. However, the limitation of using the membrane separation process is: (i) membrane fouling and hence the feed solution should have low solid contents, and it should be operated at low flow rate to minimize the fouling, and (ii) high capital cost. A recent review on MBR can be found elsewhere (Le-Clech et al., 2006).

UF refers to membranes that have pore diameters from 0.001 to 0.02 microns. UF is generally used for the separation of colloids up to a range of 0.001 to 0.1 microns. It enables the concentration, purification and fractionation of macromolecules such as proteins, dyes, and other polymeric materials. It is widely used in the industrial WWTPs where recycling of raw materials, products, and by-products are of primary concern. For example, it can be used to recover paints in the electrophoretic painting industries, and lignin and lignosulfonates from black liquor in the pulp and paper industry. UF is also used as a pretreatment to NF and RO processes (Schafer, 2001).

NF has membrane pore size in the range between UF and RO. Simpson et al. (1987) has defined NF as charged UF and is sometimes referred to as a low pressure RO. The NF can remove 50% of hardness, more than 90% of color causing substances and almost all turbidity. The NF has the advantage of low operating pressure compared to RO, and has a high rejection of organics compared to UF. Both charge and size are important in NF rejection. At a neutral pH, most NF membranes are negatively charged. At lower pH, it is positively charged (Zhu and Elimelech., 1997). Physical sieving is the dominant rejection mechanism for the colloids and large molecules. However, for the ions and lower MW organics, chemical interactions between the solutes and membrane can play an important role in rejection mechanisms.

RO was the first membrane process to be widely commercialized. Reverse osmosis is a reversal of the natural process of osmosis in which water from a dilute solution passes through a semi-permeable membrane into a more concentrated solution due to osmotic pressure. In reverse osmosis, an external pressure greater than the osmotic pressure is applied so that the water from concentrated solution passes into the diluted solution. Thus it can be used to separate salts and low MW pollutants from water and wastewater (Vigneswaran et al, 1991).

There are many references on the limits of applications or boundaries of different membranes (Vigneswaran and Ben Aim, 1989; Ho and Sirkar, 1992; Mallevalle et al., 1996; Mulder, 1996; Fane, 1996; Schafer, 2001). However, since the boundary of each membrane is uncertain, many researchers have used different definitions for the choice of membranes. Hence, it is necessary to put forward a detailed and clear definition for the pore size of the membrane. Table 1 presents the classification of different membranes, and thus would avoid overlapping of the definition of pore sizes for different membranes in terms of the tight and loose membranes.

| Membrane Process             | RO       | NF         |             | UF            |                       | MF                              |                                          |
|------------------------------|----------|------------|-------------|---------------|-----------------------|---------------------------------|------------------------------------------|
|                              |          | Tight      | Loose       | Tight         | Loose                 | Tight                           | Loose                                    |
| Molecular Weight Cutoff (Da) | < 200 Da | 200 to 300 | 300 to 1000 | 1000 to 10000 | 10000 Da to 100000 Da | 100000 Da to 0.01 $\mu\text{m}$ | 0.01 $\mu\text{m}$ to 0.05 $\mu\text{m}$ |

Table 1 Size range of membrane separation process

The major difference between different membrane processes is shown in Table 2. MF and UF can be considered as the same group due to its porous membrane type. On the other hand, NF and RO have similar characteristics of membrane material,

transport and solute removal. The major difference between NF and RO is that the membrane can remove more than 50% of divalent ions such as calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ).

The membranes can be designed for different support frames (Cardew and Le, 1998). The advantages and disadvantages of different designs of membrane in terms of MF, UF, NF and RO are given in Table 3. The selection of a membrane module is determined by economic considerations, type of application and the functionality of the module. Membrane modules are available in five different designs, flat sheet (plate and frame), hollow fiber, spiral wound, tubular and capillary (of hollow fiber design). The characteristics of the module which must be considered in a system design include packing density, investment cost, fouling tendency, cleaning, operating costs and membrane replacement cost. The qualitative comparison of various membrane configurations are given in Table 4.

| Particular                                                | MF                                                                    | UF                                           | NF                                         | RO                                                 |
|-----------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------|--------------------------------------------|----------------------------------------------------|
| Membrane                                                  | Porous isotropic                                                      | Porous asymmetric                            | Finely porous asymmetric/ composite        | Nonporous asymmetric/ composite                    |
| Transfer mechanism                                        | Sieving and adsorptive mechanisms (the solutes migrate by convection) | Sieving and preferential adsorption          | Sieving/electrostatic hydration/ diffusive | Diffusive (solutes migrate by diffusion mechanism) |
| Law governing transfer                                    | Darcy's law                                                           | Darcy's law                                  | Fick's law                                 | Fick's law                                         |
| Typical solution treatment                                | Solution with solid particles                                         | Solution with colloids and/or macromolecules | Ions, small molecules                      | Ions, small molecules                              |
| Typical pure water flux ( $\text{L}/\text{m}^2\text{h}$ ) | 500 – 10,000                                                          | 100 – 2,000                                  | 20 – 200                                   | 10 - 100                                           |
| Pressure requirement (atm)                                | 0.5 – 5                                                               | 1 – 10                                       | 7 – 30                                     | 20 - 100                                           |

Table 2 Difference between MF, UF, NF, and RO

| Design       | Advantages                      | Disadvantages                        |
|--------------|---------------------------------|--------------------------------------|
| Flat Sheet   | Wide choice of membranes        | High cost                            |
|              | Can be disassembled and cleaned | Replacing membrane is time consuming |
|              | Low energy requirement          | Can have seal problem                |
| Hollow Fiber | Very compact system             | Can be fouled with particulates      |
|              | Low liquid hold-up              | Not suitable for viscous systems     |
|              | Low capital cost                | Limited range of products            |
|              | Backflushable                   |                                      |
| Spiral Wound | Low hold-up                     | Can have dead spots                  |
|              | Compact system                  | Cannot be backflushed                |
|              | Wide range of materials         |                                      |

|         |                                                |                         |
|---------|------------------------------------------------|-------------------------|
| Tubular | Wide range of sizes                            |                         |
|         | Low capital cost                               |                         |
|         | Can tolerate feeds with high suspended solids  | High energy requirement |
|         | Can work with viscous and non-Newtonian fluids | High capital cost       |
|         | Easy to clean mechanically                     | Large space demand      |
|         |                                                | Disassembly long        |
|         |                                                | High hold-up            |

Table 3 Advantages and disadvantages of membrane designs

| Characteristics                    | Tubular | Flat sheet | Spiral wound | Capillary | Hollow fiber |
|------------------------------------|---------|------------|--------------|-----------|--------------|
| Packing density                    | Lowest  | Lower      | Low          | High      | Higher       |
| Investment cost and Installed area | Highest | Higher     | High         | Low       | Lower        |
| Fouling tendency                   | Lowest  | Lower      | Low          | High      | Higher       |
| Ease of cleaning                   | Best    | Better     | Good         | Poor      | Poorer       |
| Operating cost                     | Highest | Higher     | High         | Low       | Lower        |
| Membrane replacement               | Yes/No  | Yes        | No           | No        | No           |

Table 4. Qualitative comparison of various membrane configurations

## 2.1 Theory

The application of membrane processes in WWTPs has increased since the appearance of synthetic asymmetric membranes in 1960 (Ridgway et al., 1996). A number of mathematical models have also been developed to describe membrane filtration. The transport models developed have been classified into different groups: i) porous and nonporous membranes, ii) organic and inorganic and iii) different sizes of organic matter. However, it should be noted that a comprehensive understanding of the parameters influencing the mass transfer of solutes is invaluable to a predictive model of membrane filtration.

The transport models developed for nonporous membranes (NF and RO) consist of three types: i) homogeneous membrane models (solution-diffusion, extended solution-diffusion and solution-diffusion-imperfection models), ii) pore-based models (preferential sorption-capillary flow, finely porous and surface force-pore flow models) and iii) irreversible thermodynamic models (Kedem-Katchalsky and Spiegler-Kedem models) (Bhattacharyya and Williams, 1992). The models of porous membranes (UF and MF) can be classified into: i) basic models based on Hagen-Poiseuille equation and Kozeny-Carman relationship), ii) Knudsen flow, iii) friction model and iv) concentration polarization (CP) model (resistance in series model, osmotic pressure model and mechanistic interpretation) (Mulder, 1996).

These models can be divided into four groups in terms of organic and inorganic characteristics of solutes in Figure 1.

- (i) the non-charged colloids which follow mainly the CP relationship, convection

- and diffusion, Nernst-Plank equation, resistance in series and cake filtration theory.
- (ii) the charged colloids which involve a relationship of convection and diffusion, Donnan exclusion, extended Nernst-Plank equation, resistance in series and cake filtration theory.
  - (iii) general organic matter which follows the CP relationship, thermodynamic model, diffusivity, resistance in series and adsorption layers.
  - (iv) ions (anions) which obey Donnan exclusion and extended Nernst-Plank equation.

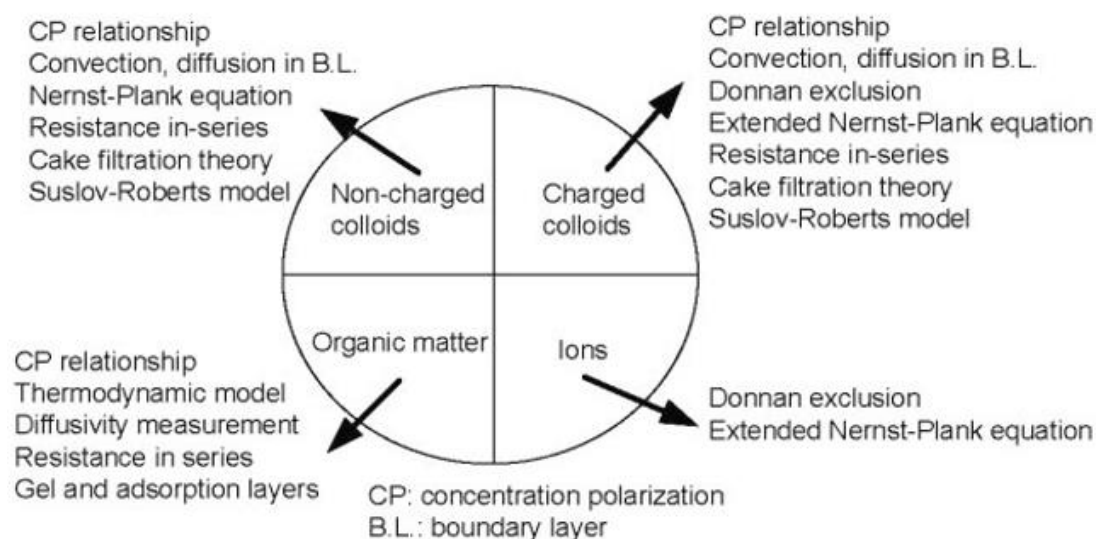


Figure 1 Concept of membrane transport phenomena in terms of different solutes

## 2.2 Membrane Fouling

Membrane fouling has been the major challenge to the better operation of the membrane processes. Membrane fouling can occur due to the following reasons: (i) biological fouling which is the growth of biological species on the membrane surface, (ii) colloidal fouling which results in a loss of permeate flux through the membrane, (iii) organic fouling due to the deposition of organic substances, and iv) scaling which is defined as the formation of mineral deposits precipitating from the feed stream to the membrane surface (Duranceau, 2001). While biofouling is important in the long term, most likely, biofouling occurs only after organic, inorganic or colloidal fouling. Since interactions between solutes and the membranes are poorly understood, it is possible that effects like charge interactions, bridging, and hydrophobic interactions may play an important role in membrane fouling. Normally, membranes with larger pores exhibit a greater flux decline as filtration proceeds. This is due to internal clogging. However, flux decline is not necessarily due to fouling. Concentration polarization or osmotic pressure or membrane compaction can appear as fouling.

Membrane foulants consist of complex compound, in a range of sizes and affected by the type of transport. As time proceeds, the foulants form different structures, type and layers on the membrane surface, depending on pressure applied and the progress of biofouling. In addition, different membranes and water characteristics form different

types of membrane foulants. This leads to a difficulty in understanding the issue of membrane foulants. Table 5 presents the distribution of reasons for selecting membrane process. Although this information applies to drinking water sources, it provides a starting point for ranking of membrane foulants in wastewater sources. The top rank reasons of selecting membrane processes are in the order of biofouling, scaling, organic fouling and particulate fouling (Mickley et al., 1993).

| Ranking | Foulants         | Foulant type                                                                                       |
|---------|------------------|----------------------------------------------------------------------------------------------------|
| 1       | Bacteria         | Biofouling (attachment -> growth -> soluble microbial products -> detachment)                      |
|         | HCO <sub>3</sub> | Scaling (precipitation of calcium carbonate by RO concentrate)                                     |
| 2       | Organics         | Organic fouling (primary cause of chronic fouling)                                                 |
|         | Turbidity        | Particulate fouling (deposition of suspended matter, colloids and micro-organisms on the membrane) |

Table 5 Distribution of reasons for selecting membrane process

Organic fouling which is the initial cause of membrane fouling is related to the molecular size, shape and chemical characteristics (steric, polar, functional group and stability to form hydrogen bond) of organic matter. The organic fouling can occur due to adsorption, precipitation, and the interactions with cations. Therefore, depending on the characteristics of the organics, the membrane type and its operating condition need to be selected. Organic fouling is normally irreversible and needs careful chemical treatment.

Membrane fouling in terms of the size of organic matter is different with MF, UF, NF and RO. Membrane fouling of MF and UF which are porous is significantly affected by suspended solid, particulate organic and large organic matter, while that of NF and RO which are non-porous and come into contact with more smaller size of organic matter due to pretreatment is caused by less than 30 kDa of organic matter. Kim et al. (2008) reported that the inorganic and organic weight percentages of the NF foulant in North Buffalo wastewater, USA after MF and UF pretreatment were nearly equal (56% vs. 44%) on the membrane surface. Extensive autopsy analyses on the NF showed there was between 35-56% less organic carbon where UF pretreatment was used rather than MF. Chellam et al. (1997) found that colloidal materials could cause more fouling than dissolved organic matter in NF. DiGiano et al. (1994) found that the molecular weight greater than 30 kDa of organic matter was responsible for NF fouling, while Kaiya et al. (1996) observed that the organic compounds with MW larger than 100 kDa are major foulants in MF. They further noticed the change in fouling mechanism after 20 h operation of NF, possibly due to the interactions of the hydrophobic and hydrophilic fractions of organics. Membrane fouling would be very severe in positively charged membranes which can attract the negatively charged organics easily (Nystrom et al., 1995).

Many researchers have suggested that the humic substances fraction of organic matter is a major foulant which controls the rate and extent of fouling (Combe et al., 1999; Jones and O'Melia, 2000; Yuan and Zydney, 1999). However, recent studies have reported that hydrophilic (non-humic) organic matter is a more significant foulant. Wiesner et al. (1992) identified that proteins, aminosugars, polysaccharides, and

polyhydroxyaromatics were strong foulants. In the studies performed by Lin et al. (2000) and Carroll et al., (2000), the rate of fouling was reduced after coagulation pretreatment. Fan et al., (2001) identified potential foulants in order as hydrophilic neutrals > hydrophobic acids > transphilic acids. Macromolecules of a relatively hydrophilic character (e.g. polysaccharides) were effectively rejected by low-pressure membranes, suggesting that macromolecular compounds and/or colloidal organic matter in the hydrophilic organic fraction may be a problematic foulant for low-pressure membranes. As the filtration through the membrane proceeds, the pore of the membrane is blocked by organic and inorganic substances reducing the effluent flux through the membrane. The blockage of the pores of the membrane is known as membrane fouling. Normally, membranes with larger pores exhibit a greater flux decline. It should be noted that the flux decline is not necessarily due to the membrane fouling only. Concentration polarization, or osmotic pressure or membrane compaction can cause flux decline. Therefore careful experimental study is necessary to distinguish membrane fouling from other effects.

Inorganic ions such as calcium, phosphorus, aluminium and iron etc. were found to enhance the membrane fouling during water treatment processes (Baker et al., 1995). Hong and Elimelech (1997) observed that membrane fouling by organic matter was increased in the presence of calcium ions, at decreased pH, and increased ionic strength. They further noted that permeation drag and electrostatic double layer repulsion controlled the membrane fouling.

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### **Bibliography**

Abdessemed D. and Nezzal G. (2002) Treatment of primary effluent by coagulation-adsorption-ultrafiltration for reuse. *Desalination*, 152, 367-373. [This presents approaches to the study of coagulation and adsorption pretreatment to UF]

Ahn K.H. and Song K.G. (1999) Treatment of domestic wastewater using microfiltration for reuse of wastewater. *Desalination*, 126, 7-14. [This presents approaches to the study of MF performance for wastewater reuse]

Alonso E., Santos A., Solis G.J. and Riesco P. (2001) On the feasibility of urban wastewater tertiary treatment by membranes: a comparative assessment. *Desalination*, 141, 39-51. [This presents approaches to the study of the assessment of membrane performance]

Amy G. and Cho J. (1999) Interactions between Natural Organic Matter (NOM) and Membranes: Rejection and Fouling. *Water Science and Technology*, 40, 131-139. [This presents approaches to the study of interactions between NOM and membranes]

Baker J., Stephenson T., Dard S., and Cote P. (1995). Characterisation of fouling of nanofiltration membranes used treat surface waters. *Environmental Technology*, 16, 977-985. [This presents approaches



to the study of fouling of NF]

Balmer M.E., Buser H.-R., Müller M.D. and Poiger T. (2005) Occurrence of Some Organic UV Filters in Wastewater, in Surface Waters, and in Fish from Swiss Lakes. *Environmental Science & Technology*, 39, 953-962. [This presents approaches to the study of organic occurrence from Swiss water system]

Belfroid A. C., Van der Horst A., Vethaak A. D., Schäfer A. J., Rijs G. B. J., Wegener J. and Cofino W. P. (1999) Analysis and occurrence of estrogenic hormones and their glucuronides in surface water and waste water in The Netherlands. *The Science of The Total Environment*, 225, 101-108. [This presents approaches to the study of analysis and occurrence of hormones]

Bellona C., Drewes J.E., Xu P. and Amy G. (2004) Factors affecting the rejection of organic solutes during NF/RO treatment—a literature review. *Water Research*, 38, 2795-2809. [This presents approaches to the study of the factors affecting the rejection of organics in NF/RO]

Ben Aim R., Liu M.G., and Vigneswaran S. (1993). Recent development of membrane processes for water and wastewater treatment. *Water Science and Technology*, 27, 141-149. [This presents approaches to the study of updated information of membrane processes]

Ben Aim R., Peuchot M. M., Vigneswaran S., Yamamoto K. and Boonthanon S. (1988) A new process for water reuse; in-line flocculation-crossflow filtration. In *Water Pollution Control in ASIA*, ed. T. Panswad, C. Polprasert, and K. Yamamoto. Bangkok. [This presents approaches to the study of in-line flocculation-crossflow filtration]

Bennie D. T. (1999) Review of the environmental occurrence of alkylphenols and alkylphenol ethoxylates. *Water Qual. Res. J. Canada*, 34, 79-122. [This presents approaches to the study of alkylphenols and alkylphenol ethoxylates occurrence]

Berg P., Hagemeyer G. and Gimbel R. (1997) Removal of pesticides and other micropollutants by nanofiltration. *Desalination*, 113, 205-208. [This presents approaches to the study of removal of micropollutants by NF]

Bernhard M., Müller J. and Knepper T.P. (2006) Biodegradation of persistent polar pollutants in wastewater: Comparison of an optimised lab-scale membrane bioreactor and activated sludge treatment. *Water Research*, 40, 3419-3428. [This presents approaches to the study of the comparison between MBR and activate sludge in removing POPs]

Bhattacharyya D. and Williams M.E. Reverse osmosis In Chapter 22. Winston Ho, W.S. and Sirkar, K.K. *Membrane handbook*. 1992. [This chapter shows RO from fundamental to applications]

Cardew P. T. and Le M.S. (1998) *Membrane Processes: A technology guide*. The Royal Society of Chemistry, UK. [This book presents general information of membrane processes]

Carroll T., King S., Gray S.R., Bolto B.A. and Booker N.A. (2000) The fouling of microfiltration membranes by NOM after coagulation treatment. *Water Research*, 34, 2861-2868. [This presents approaches to the effect of coagulation to MF]

Chang S., Waite T.D., Schäfer A.I. and Fane A.G. (2002) Adsorption of trace steroid estrogens to hydrophobic hollow fibre membranes. *Desalination*, 146, 381-386. [This presents approaches to the study of adsorption of estrogens to hollow fibre membranes]

Chapman H., Vigneswaran S., Ngo H. H., Dyer S., and Ben Aim R. (2002) Pre-flocculation of secondary treated wastewater in enhancing the performance of microfiltration. *Desalination*, 146, 367-372. [This presents approaches to the study of the effect of flocculation to MF]

Chellam S., Jacangelo J.G., Bonacquisti T.P., and Schauer B.A. (1997) Effect of pretreatment for surface water nanofiltration. *Journal of American Water Works Association*, 89, 77-88. [This presents approaches to the study of effect of pretreatment to NF]

Cheryan M. (1998). *Ultrafiltration and Microfiltration Handbook*, Technomic Publishing Co., Lancaster, PA. [This book presents detailed information of UF and MF]

Cho J. (2007) membrane selection guide. [http://env1.gist.ac.kr/~dwl/saehan\\_p/nom\\_infonews.html](http://env1.gist.ac.kr/~dwl/saehan_p/nom_infonews.html) (access on 25 December 2007). [This presents membrane selection guide]

Cho J. (2004) <http://env1.gist.ac.kr/upload/target-compounds.pdf> in <http://env1.gist.ac.kr/~dwl/> (last

access: 9<sup>th</sup> July 2008). [This website presents information of micropollutants]

Clara M., Strenn B., Gans O., Martinez E., Kreuzinger N. and Kroiss H. (2005) Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants. *Water Research*, 39, 4797-4807. [This presents approaches to the study of removal of some micropollutants in MBR and a conventional treatment plant]

Clark M.M., Baudin I. and Anselme C. Membrane-powdered activated carbon reactors. In: *Water Treatment Membrane Processes*, ed. J. Mallevialle, McGraw-Hill, New York, NY, USA, 1996. [This book chapter presents application of membrane-PAC reactors]

Combe C., Molis E., Lucas P., Riley R. and Clark M.M. (1999) The effect of CA membrane properties on adsorptive fouling by humic acid. *Journal of Membrane Science*, 154, 73-87. [This presents approaches to the study of fouling by humic acid on CA membrane]

Comerton A.M., Andrews R.C., Bagley D.M. and Yang P. (2007) Membrane adsorption of endocrine disrupting compounds and pharmaceutically active compounds. *Journal of Membrane Science*, 303, 267-277. [This presents approaches to the study of membrane adsorption of micropollutants]

DiGiano F. A., Braghetta A., Nilson J., and Utne B. (1994) Fouling of nanofiltration membranes by natural organic matter. *National Conference on Environmental Engineering*, American Society of Civil Engineers, 320-328. [This presents approaches to the study of NF fouling by NOM]

Dignac, M.F., Ginestet P., Ryback D., Bruchet A., Urbain V., and Scribe P. (2000) Fate of wastewater organic pollution during activated carbon sludge treatment: nature of residual organic matter. *Water Research*, 37, 4185-4194. [This presents approaches to the study of fate of organic matter in activated carbon sludge treatment]

Drewes J., Reinhard M. and Fox P. (2003) Comparing microfiltration-reverse osmosis and soil-aquifer treatment for indirect potable reuse. *Water Research*, 37, 3612-3621. [This presents approaches to the study of comparison of MF-RO with aquifer treatment]

Duin O., Wessels P., van der Roest H., Uijterlinde C. and Schoonewille H. (2000) Direct nanofiltration or ultrafiltration of WWTP effluent? *Desalination*, 132, 65-72. [This presents approaches to the study of comparison of NF or UF for wastewater reuse]

Durance S. J. (2001) *Membrane practices for water treatment*. Denver: American Water Works Association, 59-62. [This book is about membrane application for water treatment]

Ernst M., Sachse A., C. Steinberg E. W. and Jekel M. (2000) Characterization of the DOC in nanofiltration permeates of a tertiary effluent. *Water Research*, 34, 2879-2886. [This presents approaches to the study of characterization of organic matter after NF]

Fan L., Harris J.L., Roddick F.A. and Booker N.A. (2001) Influence of the characteristics of natural organic matter on the fouling of microfiltration membranes. *Water Research*, 35, 4455-4463. [This presents approaches to the study of effect of organic matter on MF]

Fane A.G. (1996) Membrane for water production and wastewater reuse. *Desalination* 106, 1-9. [This presents the review of membrane for water production and wastewater reuse]

Gander M., Jefferson B. and Judd S. (2000) Aerobic MBRs for domestic wastewater treatment: a review with cost considerations. *Separation and Purification Technology*, 18, 119-130. [This presents approaches to the study of review of cost effect on aerobic MBR]

Garrison A.W., Pope J.D. and Allen F.R. In: C.H. Keith, Editor, *Identification and analysis of organic pollutants in Water*, Ann Arbor Sci. Publ., Ann Arbor, MI (1976), p. 517. [This presents approaches to the study of detailed characterization of organic pollutants]

Glucina K., Laine J.M., and Robert C. (1997) Integrated, multi-objective membrane systems for surface water treatment, *Proceedings AWWA Membrane Technology Conference*, New Orleans, USA, 327-353. [This presents approaches to the study of different membrane systems for water treatment]

Göbel A., McArdell C.S., Joss A., Siegrist H. and Giger W. (2007) Fate of sulfonamides, macrolides, and trimethoprim in different wastewater treatment technologies. *Science of the Total Environment*, 372, 361-371. [This presents approaches to the study of fate of some organic compounds in terms of different

treatment]

González S., Müller J., Petrovic M., Barceló D. and Knepper T.P. (2006) Biodegradation studies of selected priority acidic pesticides and diclofenac in different bioreactors. *Environmental Pollution*, 144, 926-932. [This presents approaches to the study of biodegradation of some micropollutants in different bioreactors]

Gray S. (2003). NOM removal with membranes. *Natural organic matter in drinking water: problems and solutions*. CRC for water quality and treatment: Occasional paper 6, p. 5-9. [This presents approaches to the study of NOM removal using membranes]

Gusses A. M., Allgeier S. C., Speth T. F., and Summers R. S. (1997) Evaluation of surface water pretreatment processes using rapid bench-scale membrane test. *Proceedings, AWWA Membrane Technology Conference, New Orleans*, pp. 765-782. [This presents approaches to the study of evaluation of water pretreatment processes]

Haberkamp J., Ruhl A. S., Ernst M. and Jekel M. (2007) Impact of coagulation and adsorption on DOC fractions of secondary effluent and resulting fouling behaviour in ultrafiltration. *Water Research*, 41, 3794-3802. [This presents approaches to the study of fouling behaviour of UF in terms of DOC fractions]

Her N.G. Identification and characterization of foulants and scalants on NF membrane. Ph.D. dissertation, Department of Civil, Environmental, and Architectural engineering, University of Colorado at Boulder, 2002. [This thesis presents detailed characterization of foulants on NF membrane]

Ho W.S. and Sirkar K.K. (1992) *Membrane handbook*. Van Nostrand Reinhold, New York, USA. [This covers fundament and application of membrane processes]

Holbrook R.D., Love N.G., Novak J.T. (2003) Biological wastewater treatment and estrogenic endocrine disrupting compounds: Importance of colloid organic carbon. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, 7, 289. [This presents approaches to the study of transport of EDC compounds]

Hong S., and Elimelech M (1997) Chemical and physical aspects of natural organic matter (NOM) fouling of nanofiltration membranes. *Journal of Membrane Sciences*, 132, 159-181. [This presents approaches to the study of NOM fouling of NF]

Huang C.H. and Sedlak D.L. (2001) Analysis of estrogenic hormones in municipal wastewater effluent and surface water using enzyme-linked immunosorbent assay and gas chromatography/tandem mass spectrometry, *Environ. Toxicol. Chem.*, 20, 133-139. [This presents approaches to the study of analysis of estrogenic hormones]

Huber S. A. (1998) Evidence for membrane fouling by specific TOC constituents, *Desalination*, 119, 229-235. [This presents approaches to the study of membrane fouling by organic constituents]

Ivashechkin P., Corvini P.F.X., Fahrbach M., Hollender J., Konietzko M., Meesters R., Schröder H.F. and Dohmann M. (2004) Comparison of the elimination of endocrine disrupters in conventional wastewater treatment plants and membrane bioreactors. *Proc. IWA Leading Edge Technologies Conf.* [This presents approaches to the study of removal of EDCs]

Jarusutthirak C. (2002) Fouling and flux decline of reverse osmosis (RO), nanofiltration (NF) and ultrafiltration (UF) membranes associated with effluent organic matter (EfOM) during wastewater reclamation/reuse. Ph. D. Dissertation, University of Colorado at Boulder. [This thesis presents fouling and flux decline of RO, NF and UF]

Jarusutthirak C. and Amy G. (2001) Membrane filtration of wastewater effluents for reuse: effluent organic matter rejection and fouling. *Water Science and Technology*, 43, 225-232. [This presents approaches to the study of EfOM rejection and fouling]

Jones K.L. and Charles R. (2000) O'Melia Protein and humic acid adsorption onto hydrophilic membrane surfaces: effects of pH and ionic strength. *Journal of Membrane Science*, 165, 31-46. [This presents approaches to the study of protein and humic acid adsorption onto hydrophilic membrane]

Joss A., Keller E., Alder A.C., Göbel A., McArdell C.S., Ternes T. and Siegrist H. (2005) Removal of pharmaceuticals and fragrances in biological wastewater treatment. *Water Research*, 39, 3139-3152. [This presents approaches to the study of removal of PPCPs in biological wastewater treatment]

Joss A., Zabczynski S., Göbel A., Hoffmann B., Löffler D., McArdell C.S., Ternes T.A., Thomsen A. and Siegrist H. (2006) Biological degradation of pharmaceuticals in municipal wastewater treatment: Proposing a classification scheme. *Water Research*, 40, 1686-1696. [This presents approaches to the study of biological degradation of PPCPs]

Kaiya Y., Itoh Y., Fujita K. and Takizawa S. (1996) Study on fouling materials in the membrane treatment process for potable water. *Desalination*, 106, 71-77. [This presents approaches to the study of fouling materials in the membrane treatment process]

Kenneth O. Agenson and Taro Urase (2007) Change in membrane performance due to organic fouling in nanofiltration (NF)/reverse osmosis (RO) applications. *Separation and Purification Technology*, 55, 147-156. [This presents approaches to the study of effect of membrane fouling on organic matter]

Kim H. S., Katayama H., Takizawa S., and Ohgaki S. (2001) Removal of coliphage Q $\beta$  and organic matter from synthetic secondary effluent by powdered activated carbon-microfiltration (PAC-MF) process. *Proceedings of IWA Specialized Conference on Membrane Technology, Israel*, pp. 211-219. [This presents approaches to the study of removal of coliphage Q $\beta$  and organic matter using PAC-MF]

Kim J., DiGiano F.A. and Reardon R.D. (2008) Autopsy of high-pressure membranes to compare effectiveness of MF and UF pretreatment in water reclamation. *Water Research*, Doi: 10.1016/j.watres.2007.08.042. [This presents approaches to the study of comparison of MF and UF pretreatment]

Kim S.L., Chen J.P. and Ting Y.P. (2002) Study on feed pre-treatment for membrane filtration of secondary effluent. *Separation and Purification Technology* 29, 171-179. [This presents approaches to the study of feed pretreatment for membrane filtration]

Kimura K., Amy G., Drewes J.E., Heberer T., Kim T.-U. and Watanabe Y. (2003) Rejection of organic micropollutants (disinfection by-products, endocrine disrupting compounds, and pharmaceutically active compounds) by NF/RO membranes. *Journal of Membrane Science*, 227, 113-121. [This presents approaches to the study of rejection of organic micropollutants by NF/RO membranes]

Kimura K., Hara H. and Watanabe Y. (2005) Removal of pharmaceutical compounds by submerged membrane bioreactors (MBRs). *Desalination*, 178, 135-140. [This presents approaches to the study of removal of PPCPs by MBRs]

Kimura K., Hara H., and Watanabe Y. (2007) Elimination of Selected Acidic Pharmaceuticals from Municipal Wastewater by an Activated Sludge System and Membrane Bioreactors. *Environmental Science & Technology*, 41, 3708 - 3714. [This presents approaches to the study of removal of selected PPCPs from activated sludge and MBR treatment]

Kishino H., Ishida H., Iwabu H. and Nakano I. (1996) Domestic wastewater reuse using a submerged membrane bioreactor. *Desalination*, 106, 115-119. [This presents approaches to the study of MBR for wastewater reuse]

Kiso Y., Kon T., Kitao T. and Nishimura K. (2001a) Rejection properties of alkyl phthalates with nanofiltration membranes. *Journal of Membrane Science*, 182, 205-214. [This presents approaches to the study of rejection properties with NF]

Kiso Y., Mizuno A., Othman R.A.A., Jung Y.-J., Kumano A. and Arijji A. (2002) Rejection properties of pesticides with a hollow fiber NF membrane (HNF-1), *Desalination*, 148, 147-157. [This presents approaches to the study of rejection properties of pesticides with a hollow fiber NF]

Kiso Y., Sugiura Y., Kitao T. and Nishimura K. (2001b) Effects of hydrophobicity and molecular size on rejection of aromatic pesticides with nanofiltration membranes. *Journal of Membrane Science*, 192, 1-10. [This presents approaches to the study of effect of hydrophobicity and molecular size on rejection of aromatic pesticides with NF]

Kolpin D.W., Furlong E.T., Meyer M.T., Thurman E.M., Zaugg S.D., Barber L.B. and Buxton H.T. (2002) Pharmaceuticals, hormones and other organic waste contaminants in U.S. streams, 1999-2000: A national reconnaissance. *Environmental Science & Technology*, 36, 1202-1211. [This presents approaches to the study of Pharmaceuticals, hormones and other organic waste contaminants in U.S. streams]

Laabs C., Amy G. and Jekel M. (2006) Understanding the size and character of fouling-causing substances

from effluent organic matter (EfOM) in low-pressure membrane filtration. *Environmental Science & Technology*, 40, 4495-4499. [This presents approaches to the study of effect of the size and character of foulant]

Le-Clech P., Chen V. and Fane A.G. (2006) Fouling in membrane bioreactors used in wastewater treatment. *Journal of Membrane Science*, 284, 17-53. [This presents approaches to the study of fouling in MBR]

Lee J., Lee B.C., Ra J.S., Cho J., Kim I.S., Chang N.I., Kim H.K. and Kim S.D. (2008) Comparison of the removal efficiency of endocrine disrupting compounds in pilot scale sewage treatment processes. *Chemosphere*, In Press, Corrected Proof, Available online 26 December 2007. [This presents approaches to the study of comparison of the removal efficiency of EDC]

Lee N.H., G. Amy, J.-P. Croué and H. Buisson (2004) Identification and understanding of fouling in low-pressure membrane (MF/UF) filtration by natural organic matter (NOM), *Water Research*, 38, 4511-4520. [This presents approaches to the study of fouling in (MF/UF) filtration]

Lee S. (2004) Transport characteristics and sherwood correlation of natural organic matter in nanofiltration and ultrafiltration membranes. Doctoral thesis of philosophy, Gwangju Institute of Science and Technology, 44-70. [This presents approaches to the study of natural organic matter correlation in (NF/UF) membranes]

Lee S., Cho Y.G., Song Y., Kim I.S. and Cho J. (2003) Transport characteristics of wastewater effluent organic matter in nanofiltration and ultrafiltration membranes. *Journal of Water Supply*, 52, 129-139. [This presents approaches to the study of transport characteristics of wastewater effluent organic matter in (NF/UF) membranes]

Levenstein R., Hasson D., and Semiat R. (1996) Utilization of the Donnan effect for improving electrolyte separation with nanofiltration membranes. *Journal of Membrane Science*, 116, 77-92. [This presents approaches to the study of improving electrolyte separation using Donnan effect]

Levine B.B., Madhiredi K., Lazarova V., Stenstrom M.K. and Suffet M. (1999) Treatment of trace organic compounds by membrane processes: at the lake arrowhead water reuse pilot plant. *Water Science and Technology*, 40, 293-302. [This presents approaches to the study of treatment of trace organic compounds for water reuse]

Li W., Ma Y., Guo C., Hu W., Liu K., Wang Y. and Zhu T. (2007) Occurrence and behavior of four of the most used sunscreen UV filters in a wastewater reclamation plant. *Water Research*, Volume, 41, 3506-3512. [This presents approaches to the study of occurrence and behavior of sunscreen UV filters in a wastewater]

Lin C.F., Lin T.Y. and Hao O.J. (2000) Effects of humic substance characteristics on UF performance. *Water Research*, 34, 1097-1106. [This presents approaches to the study of effect of humic substance characteristics on UF]

López-Ramírez J.A., Sahuquillo S., Sales D. and Quiroga J.M. (2003) Pre-treatment optimisation studies for secondary effluent reclamation with reverse osmosis. *Water Research*, 37, 1177-1184. [This presents approaches to the study of pre-treatment optimization studies with RO]

Mallevialle J., Odendaal P.E. and Wiesner M.R. (1996) *Water treatment membrane processes*. McGraw-Hill, New York, USA. [This presents approaches to the study of water treatment membranes]

Matamoros V., García J. and Bayona J.M. (2008) Organic micropollutant removal in a full-scale surface flow constructed wetland fed with secondary effluent *Water Research*, In Press, Corrected Proof, Available online 24 August 2007. [This presents approaches to the study of organic micropollutant removal in wetland]

Matsui Y., Colas F. and Yuasa A. (2001b) Removal of a synthetic organic chemical by PAC-UF systems – II: Model application. *Water Research*, 35, 464-470. [This presents approaches to the study of model application of organic chemical removal using PAC-UF]

Matsui, Y., Yuasa, A., and Ariga, K. (2001a). Removal of a synthetic organic chemical by PAC-UF systems –I: theory and modeling. *Water Research*, 35, 455-463. [This presents approaches to the study of theory and modeling of organic chemical removal by PAC-UF]

- Mickley M., Hamilton R. and Truesdall J. (1993) Membrane concentrate disposal, AWWA Research Foundation, Denver. [This presents approaches to the study of disposal of membrane concentrate]
- Miura Y., M. N. Hiraiwa, T. Ito, T. Itonaga, Y. Watanabe and S. Okabe (2007) Bacterial community structures in MBRs treating municipal wastewater: Relationship between community stability and reactor performance. *Water Research*, 41, 627-637. [This presents approaches to the study of MBRs in municipal waste water treatment]
- Mulder M. (1996) Basic principles of membrane technology. Kluwer Academic Publishers, Dordrecht, The Netherlands. [This presents approaches to the study of basic principles of membrane technology]
- Nakatsuka S. and Ase T. Ultrafiltration of River Water for Drinking Water Production, Cho J. (2004) Membrane technology. Shin-Kwang Publisher. Seoul, Korea. [This presents approaches to the study of treatment of River Water for drinking purposes using UF]
- Newcombe G. (1999). Charge vs porosity: some influences on the adsorption of natural organic matter (NOM) by activated carbon. *Water Science and Technology*, 40, 191-198. [This presents approaches to the study of the influences on the adsorption of NOM by activated carbon]
- Nghiem L.D. and Hawkes S. (2007a) Effects of membrane fouling on the nanofiltration of trace organic contaminants. The 6th International Membrane Science and Technology Conference (UNSW, Sydney), 5-9 Nov., 2007. [This presents approaches to the study of membrane fouling of traces organic contaminants using NF]
- Nghiem L.D., Manis A., Soldenhoff K. and Schäfer (2004) Estrogenic hormone removal from wastewater using NF/RO membranes. *Journal of Membrane Science*, 242, 37-45. [This presents approaches to the study of using NF/RO in wastewater for hormone removal]
- Nghiem L.D., Schäfer A.I. and Waite T.D. (2002) Adsorptive interactions between membranes and trace contaminants. *Desalination*, 147, 269-274. [This presents approaches to the study of adsorptive interactions between membranes and trace contaminants]
- Nghiem L.D., Tadkaew N. and Sivakumar M. (2007b) Removal of trace organic contaminants by submerged membrane bioreactors. The 6th International Membrane Science and Technology Conference (UNSW, Sydney), 5-9 Nov., 2007. [This presents approaches to the study of removal trace organic contaminants by MBR]
- Nystrom M., Kaipia L., and Luques S. (1995) Fouling and retention of nanofiltration membranes. *Journal of Membrane Science*, 98, 249-262. [This presents approaches to the study of fouling and retention of NF]
- Pirbazari, M., Badriyha, B. N., and Ravindran, V. (1992) MF-PAC for treating waters contaminated with natural and synthetic organics. *Journal of American Water Works Association*, 84, 95-103. [This presents approaches to the study of using MF-PAC for treating contaminated waters]
- Radjenovic J., Petrovic M. and Barcelo D. (2007) Analysis of pharmaceuticals in wastewater and removal using a membrane bioreactor. *Analytical and Bioanalytical Chemistry*, 387, 1354-1377. [This presents approaches to the study of pharmaceuticals removal in wastewater using MBR]
- Ridgway H.F., Flemming H.C. and Mallevialle J. Water treatment: membrane processes, American Water Works Association, Lyonnaise des Eaux and Water Research Commission of South Africa, New York, 6.2-6.20, 1996. [This presents approaches to the study of membrane process for water treatment]
- Rosenberger S., Laabs C., Lesjean B., Gnirss R., Amy G., Jeke M. and Schrotter J.-C. (2006) Impact of colloidal and soluble organic material on membrane performance in membrane bioreactors for municipal wastewater treatment. *Water Research*, 40, 710-720. [This presents approaches to the study of performance impact of different NOMs in MBR using municipal wastewater]
- Schafer A.I. (2001) Natural organics removal using membranes: principles, performance, and cost. Technomic Publishing Company, Inc., Pennsylvania, USA. [This presents approaches to the study of the characteristics of different membranes for removal of NOM]
- Schäfer A.I., Mauch R., Waite T. D., and Fane A.G. (2002) Charge Effects in the Fractionation of Natural Organics Using Ultrafiltration. *Environmental Science & Technology*, 36, 2572 -2580. [This presents approaches to the study of charge effects using UF for NOMs fractionations]

Shon H.K., S. Vigneswaran and S.A. Snyder. (2006) Effluent organic matter (EfOM) in wastewater: constituents, effects and treatment. *Critical Reviews in Environmental Science and Technology*, 36, 327-374. [This presents approaches to the study of characteristics of EfOM in wastewater]

Shon H.K., Vigneswaran S., Ben Aim R., Ngo H. H., Kim In S. and Cho J. (2005) Influence of flocculation and adsorption as pretreatment on the fouling of ultrafiltration and nanofiltration membranes: application with biologically treated sewage effluent. *Environmental Science & Technology*, 39, 3864-3871. [This presents approaches to the study of the influences of pretreatment methods on the fouling of UF/NF using BTSE]

Shon H.K., Vigneswaran S., Kim In S., Cho J., Ngo H.H. and Johnston A. (2006) Performance of flocculation and adsorption pretreatments to ultrafiltration of biologically treated sewage effluent: the effect of seasonal variations, *Separation Science and Technology*, 41, 3585-3596. [This presents approaches to the study of the performance of pretreatment methods to UF using BTSE]

Shon H.K., Vigneswaran S., Ngo H.H., Kim D.H., Park N.E., Jang N.J. and Kim I.S. (2003) Characterization of effluent organic matter (EfOM) of fouled nanofilter (NF) membranes, *International membrane science and technology (IMSTEC) proceedings*, Sydney, Australia. [This presents approaches to the study of characterization of EfOM of fouled NF]

Simpson A.E., Kerr C.A., Buckley C.A. (1987) The effect of pH on the nanofiltration of the carbonate system in solution. *Desalination*, 64, 305-319. [This presents approaches to the study of the pH effect of carbonate system on NF]

Snyder S.A., Adham S., Redding A.M., Cannon F.S., DeCarolis J., Oppenheimer J., Wert E.C. and Yoon Y. (2007) Role of membranes and activated carbon in the removal of endocrine disruptors and pharmaceuticals. *Desalination*, 202, 156-181. [This presents approaches to the study of the removal of micropollutants using membranes and activated carbon]

Snyder S.A., Snyder E., Villeneuve D., Kurunthachalam K., Villalobos A., Blankenship A. and Giesy J. In *Analysis of Environmental Endocrine Disruptors* Keith, L. H., Jones-Lepp, T. L., Needham, L. L., Eds.; American Chemical Society: Washington, DC, 2000; pp 73-95. [This presents approaches to the study of Environmental Endocrine Disruptors Keith analysis]

Snyder S.A., Westerhoff P., Yoon Y. and Sedlak D.C. (2003b) Pharmaceuticals, personal care products and endocrine disruptors in water: implications for water industry. *Environmental Engineering Science*, 20, 449-469. [This presents approaches to the study of pharmaceuticals, personal care products and endocrine disruptors in water treatment ]

Snyder, S.A., Leising, J., Westerhoff, P., Yoon, Y., Mash, H., and Vanderford, B. (2004) Biological and Physical Attenuation of Endocrine Disruptors and Pharmaceuticals: Implications for Water Reuse. *Ground Water Monitoring and Remediation®*, 24, 108-118. [This presents approaches to the study of characteristics of Endocrine Disruptors and Pharmaceuticals for water reuse]

Spring A.J., Bagley D.M., Andrews R.C., Lemanik S. and Yang P. (2007) Removal of endocrine disrupting compounds using a membrane bioreactor and disinfection. *Journal of Environmental Engineering and Science*, 6, 131-137. [This presents approaches to the study of using MBR and disinfection to remove endocrine disrupting compounds ]

Stumm-Zollinger and Fair G.M., (1965) Biodegradation of steroid hormones, *J. Water Pollut. Cont. Fed.*, 37, 1506-1510. [This presents approaches to the study of steroid hormones biodegradation]

Tanninen J., Kamppinen L. and M. Nyström. Pretreatment/hybrid processes. Chapter 10 in Schaefer A., Fane A. and Waite T. *Nanofiltration: principles and applications*. Elsevier, 2004. [This presents approaches to the study of principles and applications of NF]

Tchobanoglous G., Darby J., Bourgeois K., McArdle J., Genest P. and Tylla M. (1998) Ultrafiltration as an advanced tertiary treatment process for municipal wastewater. *Desalination*, 119, 315-321. [This presents approaches to the study of using UF for municipal wastewater]

Ternes T., Bonerz M. and Schmidt T. (2001) Determination of neutral pharmaceuticals in wastewater and rivers by liquid chromatography-electrospray tandem mass spectrometry, *J. Chromatogr. A* 938, 175-185. [This presents approaches to the study of neutral pharmaceuticals occurrence in wastewater and rivers]

Ternes T.A. (1998) Occurrence of drugs in German sewage treatment plants and rivers, *Water Research*,

32, 3245–3260. [This presents approaches to the study of drug occurrence in German sewage treatment plants and rivers]

Ternes T.A., in: C.G. Daughton, T.L. Jones-Lepp (Eds.), *Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issue*, ACS Symposium Series 2001, ISBN: 0-8412-3739-5. [This presents approaches to the study of scientific and regulatory issues of pharmaceuticals and personal care products]

Ternes T.A., Joss A. and Siegrist H. (2004) Scrutinizing Pharmaceuticals and Personal Care Products in Wastewater Treatment. *Environ. Sci. Technol. A*-Pages, 38, 392A-399A. [This presents approaches to the study of scrutinizing pharmaceuticals and personal care Products in wastewater treatment]

Thorson T., Krogh T. and Bergan E. (1993) Removal of humic substances with membranes system, use and experiences. *Proceedings of AWWA Membrane Technology Conference*, Baltimore, USA, 131-143. [This presents approaches to the study of using of membrane systems for humic substances removal]

Urase T., Kagawa C. and Kikuta T. (2005) Factors affecting removal of pharmaceutical substances and estrogens in membrane separation bioreactors. *Desalination*, 178, 107-113. [This presents approaches to the study of factors affecting the removal of micropollutants in MSBR]

Vanderford, B.J., Pearson, R.A., Rexing, D.J., and Snyder, S.A. (2003) Analysis of endocrine disruptors, pharmaceuticals, and personal care products in water using liquid chromatography/tandem mass spectrometry. *Analytical Chemistry*, 75, 6265-6274. [This presents approaches to the study of micropollutants analysis in water using LG/ TMS]

Vigneswaran S. and Ben Aim R. (1989) *Water, wastewater, and sludge filtration*. CRC Press, Inc., Boca Raton, Florida, USA. [This presents approaches to the study of water, wastewater, and sludge filtration]

Vigneswaran S., Chaudhary D.S., Ngo H.H., Shim W.G., and Moon H. (2003). Application of a PAC-Membrane Hybrid System for Removal of Organics from Secondary Sewage Effluent: Experiments and Modelling. *Separation Science and Technology*, 38, 2183-2199. [This presents approaches to the study of removal of NOMs using PAC-membrane hybrid system]

Vigneswaran S., Vigneswaran B., and Ben Aim R. (1991). Application of microfiltration for water and wastewater treatment. *Environmental Sanitation Reviews*, 31, June. [This presents approaches to the study of using of MF for water and wastewater treatment]

Wang Y.Q., Hu W., Cao Z.H., Fu X.Q. and Zhu T., (2005) Occurrence of endocrine-disrupting compounds in reclaimed water from Tianjin, China, *Anal. Bioanal. Chem.* 383, 857–863. [This presents approaches to the study of occurrence of micropollutants in reclaimed water]

Water Environment Federation. 2006, *Membrane systems for wastewater treatment* / New York, McGraw-Hill Professional; London: McGraw-Hill [distributor], USA. [This presents approaches to the study of membrane systems for wastewater treatment]

Wiesner M.R., Clark M.M., Jacangelo J.G., Lykins B.W., Marinas B.J., O'Melia C.R., Rittmann B.E. and Semmens M.J. (1992) Committee report: Membrane processes in potable water treatment. *J. AWWA*, 59-67. [This presents approaches to the study of membrane processes in potable water treatment]

Wiesner, M. R., Clark, M. M, and Mallevialle, J. (1989) Membrane filtration of coagulated suspensions. *Journal of Environmental Engineering*, 115, 20-40. [This presents approaches to the study of coagulated suspensions using membrane filtration]

Wintgens, T.; Lyko, S.; Melin, T.; Schäfer, A.I.; Khan, S.; Sherman, P.; Ried, A. (2004) Removal of estrogenic trace contaminants from wastewater and landfill leachate with advanced treatment processes. *Proc. IWA Leading Edge Technologies Conf.* [This presents approaches to the study of using advanced treatment processes to remove micropollutants from wastewater and landfill leachate]

Yoon Y, Westerhoff P., Yoon J. and Snyder S.A. (2004) Removal of 17 $\beta$  Estradiol and Fluoranthene by Nanofiltration and Ultrafiltration. *Journal of Environmental Engineering*, 130, 1460-1467. [This presents approaches to the study of removal of 17 $\beta$  Estradiol and Fluoranthene by NF/UF]



Yoon Y., Westerhoff P., Snyder S., Song R. and Levine B. (2002) A Review on removal of endocrine-disrupting compounds and pharmaceuticals by drinking water treatment processes. Proc. AWWA Water Quality Technology Conference. [This presents approaches to the study of removal of micropollutants using drinking water treatment processes]

Yoon Y., Westerhoff P., Snyder S.A. and Wert E.C. (2006) Nanofiltration and ultrafiltration of endocrine disrupting compounds, pharmaceuticals and personal care products. Journal of Membrane Science, 270, 88-100. [This presents approaches to the study of NF/UF of micropollutants]

Yoon Y., Westerhoff P., Snyder S.A., Wert E.C. and Yoon J. (2007) Removal of endocrine disrupting compounds and pharmaceuticals by nanofiltration and ultrafiltration membranes. Desalination, 202, 16-23. [This presents approaches to the study removing of micropollutants by NF/UF]

Yuan W. and Zydney A.L. (1999) humic acid fouling during microfiltration. Journal of Membrane Science, 157, 1-12. [This presents approaches to the study of fouling of humic acid during MF]

Zhu X. and Elimelech M. (1997) Colloidal fouling on reverse osmosis membranes: measurements and fouling mechanisms. Environmental Science and Technology, 31, 3654-3662. [This presents approaches to the study of measurement and fouling mechanisms of RO]

### Biographical Sketches

**Dr H.K. Shon** is currently a UTS Chancellor's postdoctoral research since 2006. His research interests include membrane processes and new analytical methods for wastewater treatment and reuse. He has made significant contributions to the understanding of membrane fouling in wastewater treatment processes.

**Dr S. Vigneswaran** has been working on water and wastewater treatment and reuse related research since 1976. During the last twenty years, he has made significant contributions in physico-chemical water treatment related processes such as filtration, flocculation, membrane-filtration and adsorption. His research activities both on new processes development and mathematical modeling are well documented in reputed international journals such as Water Research, American Institute of Chemical Engineers Journal, Chemical Engineering Science, Journal of American Society of Civil Engineers, and Journal of Membrane Science. He has also been involved in a number of consulting activities in this field in Australia, Indonesia, France, Korea, and Thailand through various national and international agencies. He has authored two books in this field at the invitation of CRC press, USA, and has published more than 230 papers in journals and conference's proceedings. Currently a Professor of the Environmental Engineering Group at the University of Technology, Sydney, he was the founding Head of and the founding Co-ordinator of the University Key Research Strength Program in Water and Waste Management. He is coordinating the Urban Water Cycle and Water and Environmental Management of the newly established Research Institutes on Water and Environmental Resources Management and Nano-scale Technology respectively.

**Dr J. Cho**, associate professor at Gwangju Institute of Science and Technology, has been studying on research for water reuse using various technologies, including constructed wetland and membrane filtration. He is recently interested in research of ecological engineering as well as related education. He is an editorial board member of Journal, Water Science and Technology, IWA and newsletter editor of Water Reuse Specialty Group in IWA.

**Dr J. Kandasamy** is Senior Lecturer in the Faculty of Engineering University of Technology, Sydney, Australia. He obtained his PhD from University of Auckland., New Zealand where is also obtained his Bachelor in Civil Engineering and Masters in Civil Engineering. He has worked in the New South Wales Government as a Senior Engineer for 15 years and has wide industry knowledge.