MEMBRANE SCIENCE AND TECHNOLOGY FOR WASTEWATER RECLAMATION

A.F. Ismail and E. Yuliwati
Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia (UTM), 81310, Johor Bahru, Malaysia

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Contents

Summary

Wastewater is widely recognized as one of significant, growing and reliable water sources. Wastewater production is the only potential water source which will increase as the population grows and the demand on fresh water increases. The management of wastewater reclamation has basic scope of balancing water availability and water demand, at reasonable cost and with acceptable environmental impacts. Wastewater reclamation technology needs to be appropriate and sustainable, operated and maintained easily, and very efficient in removing organic matter and pathogens present in wastewaters.

This chapter extensively discusses the potential of implementing membrane technology in wastewater reclamation. By taking into consideration for the need of wastewater reclamation process that should be known the wastewater characteristic, type of membrane processes and commercial application of membrane technology. Although membrane technologies became commercially available more than 30 years ago, it is experiencing rapid development and improvements. A wide variety of membrane processes can be categorized according to driving force, membrane material, membrane type and configuration, removal capabilities and mechanism, and membrane fouling and cleaning. For example pressure driven, membrane processes include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). Among these membrane processes, membrane bioreactor (MBR) and reverse osmosis (RO) processes are well suited for application of wastewater reclamation process due to their effective energy requirement, compact configuration and high quality product.

Consider the energy requirement, the existing conventional wastewater reclamation system effluent after secondary and tertiary treatment need high energy requirement and step processes due to supply water for removal of biodegradable organic matter (in solution or suspension) and suspended solids. It is costly and has a large footprint in installation of reclaimed water distribution system. Having seen disadvantages given by

conventional wastewater reclamation process, it is necessary to propose the use of membrane technology that can be implemented efficiency from the technological and economical perspectives.

1. Introduction

The feasibility and reliability of providing adequate quantities and quality of water to meet societal needs is constrained by geographic, hydrologic, economic, and social factors. Projections of unprecedented global population growth, particularly in urban areas, have fueled concerns about water availability in increasingly complex environmental, economic, and social settings. To address the environmental, social, and economic impacts of water resources development and avert the ominous prospects of water scarcity, there is a critical need to reexamine the water resources systems.

The local water resourcing problems can provide sufficient motivation for recycling in their own right. Water scarcity can be assessed simply through the ratio of total freshwater abstraction of total resources, and can be used to indicate the availability of water and the pressure on water resources. Water stress occurs when the demand for water exceeds the availability amount when poor quality restricts its use. It provides an indication of how the total water demand puts pressure on the water resource.

Moreover, the emerging paradigm of sustainability water resources management emphasizes whole system solution to reliably and equitably meet the water needs of present and future generations. Understanding the concepts of sustainable water resources management as a foundation of water reclamation is of fundamental importance. The principle of sustainability is defined as 'Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of the future generations to meet their own needs' (Sikdar 2005).

Therefore, the goal of sustainable water resources development and management is to meet water needs reliably and equitably for current and future generations by designing integrated and adaptable systems, optimizing water-use efficiency, and making continuous efforts toward preservation and restoration of natural ecosystems. The transition to a sustainable society poses a number of technological and social challenges. Technological innovations can help to improve the considerations for sustainability that must include energy and resource use and environmental pollution (Hermanowicz 2005).

W ater reclamation is a process by which wastewater from homes and businesses is cleaned using biological and chemical treatment so that the water can be returned to the environment safely to augment the natural systems. The factors that should be included in decisions on wastewater reclamation process include contaminant removal, source water quality, reliability, existing conditions, process flexibility, utility capabilities, costs, environmental compatibility, distribution system wastewater quality, and issues of process scale. Based on these factors, the progress of technological development on wastewater reclamation is viewed by membrane technology that has tremendous potential resulting from universal capabilities and competitive costs.

Membranes have gained also an important place in wastewater reclamation process and are used in a broad range of applications. As a relatively new technology, membranes have often been disregarded in the past in favor of conventional biotreatment plants. However, a number of indicators suggest that membranes are now being accepted increasingly as the technology of choice.

Membrane technology offered as an alternative non-conventional wastewater treatment due to dynamic development of secondary and advanced wastewater treatment process. The usage of the reclaimed water decreases the pollution sent to sensitive environments. Membrane technology helps decrease diverging water from sensitive eco-systems which depend greatly on the flow to improve the quality of the water. Energy requirement of the treatment process is low compared to other alternatives of augmentation of water supply. Advances in membrane technology for wastewater reclamation contributed to its increasing recognition as reliable technology for cost effective production of high quality effluents.

Total population living in water-stressed area is expected to increase more than 20% by 2025 (IWMI 2000). The capacity of effluent wastewater becomes also increase due to retrofit and upgrade, normally relating to a requirement for improved effluent water quality without incurring a larger footprint. It is expected that opportunities for application of membrane technology will be accepted. To consider the energy requirement, the existing conventional wastewater reclamation system effluent after secondary treatment need very high energy requirement.

Moreover, the treatment of wastewater reclamation beyond secondary treatment can be costly and energy intensive due to removal of biodegradable organic matter (in solution or suspension) and suspended solids. The tertiary or advanced treatment of wastewater reclamation also needs many steps to remove the bacteria, reduce suspended solid after secondary treatment, and disinfect water to produce useable water. It is also costly and needs a large footprint in installation of reclaimed water distribution systems.

Having seen disadvantages given by conventional wastewater reclamation processes due to their low cost-effectiveness and reliability, it is necessary to offer an overview on advanced treatment technology, including membrane technology.

2. Wastewater Reclamation: An Overview

Wastewater is essentially the water supply of the community after it has been used in a variety of applications such as combination of the liquid or water-carried wastes removed from residences, institutions, and commercial and industrial establishments. They may be present as groundwater, surface water, and storm water. Wastewater contains numerous pathogenic microorganisms and also nutrients, which can stimulate the growth of aquatic plants.

Wastewater may contain toxic compounds or compounds that potentially may be mutagenic and carcinogenic. For these reasons, the removal of wastewater from its source of generation, followed by treatment, reuse or dispersal into the environment is important to protect public health and the environment.

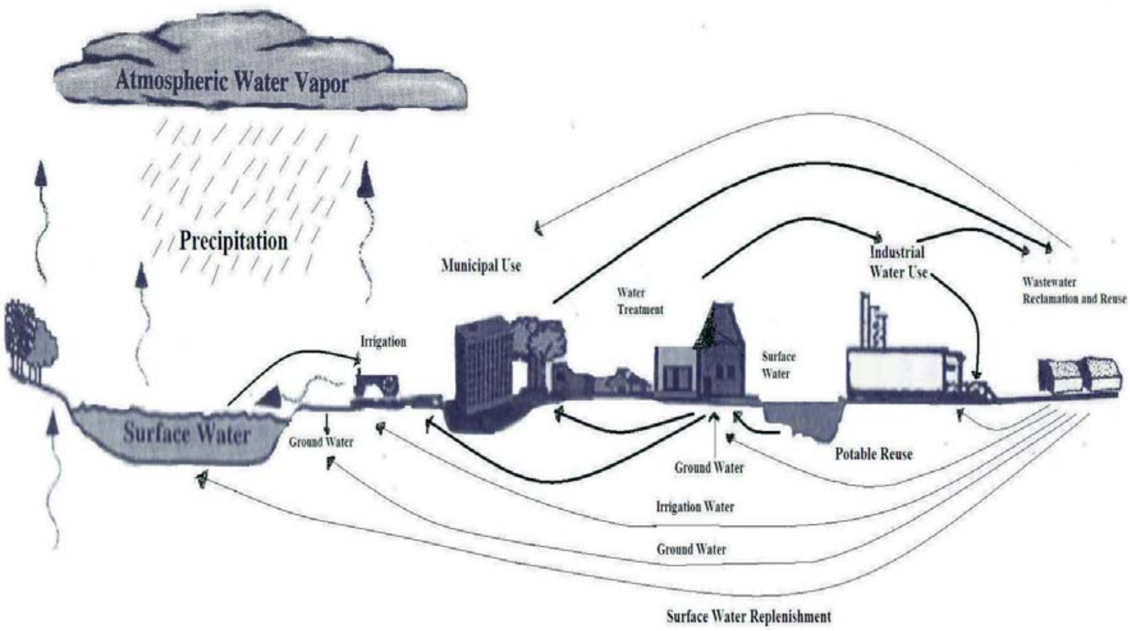

Figure 1. Role engineered treatment, reclamation, and reuse facilities in the cycling of water

2.1. The Fundamentals of Wastewater Reclamation

Wastewater reclamation is the treatment or processing of wastewater to make it reusable with definable treatment reliability and meeting water quality criteria. The benefits of wastewater reclamation and factors driving its future are summarized in Table 1.

Rationale for wastewater reclamation
• Wastewater is a limited resource. Increasingly, society no longer has the luxury of using water only once. • Acknowledge that water recycling is already happening and do it more and better. • The quality of reclaimed wastewater is appropriate for many non-potable applications such as irrigation and industrial cooling and cleaning water, thus providing a supplemental water source that can result in more effective and efficient use of water. • To meet the goal of water resource sustainability it is necessary to ensure that water is used efficiently. • Water reclamation and reuse allow more efficient use of energy and resources by tailoring treatment requirements to serve the end-users of the water. • Water reuse allows the protection of environment by reducing the volume of treated effluent discharged to receiving waters.
Potential benefits of wastewater reclamation
• Conservation of fresh water supplies. • Management of nutrients that may lead to environmental degradation. • Improved protection of sensitive aquatic environments by reducing effluent discharges. • Economic advantages by reducing the need for supplemental water sources and associated infrastructure. Reclaimed water is available near urban development where water supply reliability is most crucial and water is priced highest. • Nutrients in reclaimed water may offset the need for supplemental fertilizers, thereby conserving resources. Reclaimed water originating from treated effluent contains nutrients; if this water is used to irrigate agricultural land, less fertilizer is required for crop growth. By reducing nutrient (and resulting pollution) flows into waterways, tourism, and fishing industries are also helped.

Factors driving further implementation of wastewater reclamation
• Proximity: Reclaimed water is readily available in the vicinity of the urban environment, where water resources are most needed and are highly priced. • Dependability: Reclaimed water provides a reliable water source, even in drought years, as production of urban wastewater remains nearly constant. • Versality: The wastewater treatment process is available to provide water of nonpotable applications and can produce water of quality that meets drinking water requirements. • Safety: Nonpotable water reuse systems have been in operation for over four decades with no documented adverse public health impacts in many countries. • Increasing pressure on existing water resources due to population growth and increased agricultural demand. • Public interest: Increasing awareness of the environmental impacts associated with overuse of water supplies, and community enthusiasm for the concept of water reclamation. • Environmental and economic impacts of traditional water resources approaches: Greater recognition of the environmental and economic costs of water storage facilities such as dams and reservoirs. • More stringent water quality standards: Increased costs associated with upgrading wastewater treatment facilities to meet higher water quality requirements for effluent disposal. • Necessity and opportunity: Motivating factors for development of water reclamation projects such as droughts, water shortages, prevention of seawater intrusion and restrictions on wastewater effluent discharges, plus economic, political, and technical conditions favorable to water reclamation.

Table 1. The benefits of wastewater reclamation and driving factors (Asano 1998, Asano et al 2007)

Methods of reclamation in which removal of contaminants is brought about by chemical or biological reactions are known as unit processes. At the present time, unit operations and processes are grouped together to provide various levels of treatment known as preliminary, primary, advanced primary, secondary (without or with nutrient removal), and advanced (or tertiary) treatment as shown in Table 2.

Treatment level	**Description**
Preliminary	Removal of wastewater constituents such as rags, sticks, floatables, grit, and grease that many cause maintenance or operational problems with the treatment operations, processes, and ancillary systems.
Primary	Removal of a portion of the suspended solids and organic matter from the wastewater.
Advanced primary	Enhanced removal of suspended solids and organic matter from the wastewater. Typically accomplished by chemical addition or filtration.
Secondary	Removal of biodegradable organic matter (in solution or suspension) and suspended solids. Disinfection is also typically included in the definition of conventional secondary treatment.
Secondary with nutrient removal	Removal of biodegradable organics, suspended solids, and nutrients (nitrogen, phosphorus, or both nitrogen and phosphorus).
Tertiary and advanced	Removal of residual suspended solids (after secondary treatment), remaining after normal biological treatment

	when required for various water reuse applications. Disinfection is also typically a part of tertiary treatment. Nutrient removal is often included in this definition.

Table 2. Levels of the wastewater reclamation

In preliminary treatment, gross solids such as large objects, rags, and grit that may damage equipment are removed. In primary treatment, a physical operation, usually sedimentation is used to remove the floating and settle the materials found in wastewater as shown in Figure 2.

Figure 2. Sedimentation tanks (Wikipedia 2010)

For advanced primary treatment, chemicals are added to enhance the removal of suspended solids and, to a lesser extend, dissolved solids. In secondary treatment, biological and chemical processes are used to remove most of the organic matter. In advanced treatment, additional combinations of unit operations and processes are used to remove residual suspended solids and other constituents that are not reduced significantly by conventional secondary treatment.

2.1.1. Evolution of Wastewater Reclamation

Indication of the use of wastewater for agricultural irrigation extends back approximately 3000 years to the Minoan Civilization in Crete, Greece (Angelakis 2003). In modern times, the beginnings of water reclamation can be traced to the mid-nineteenth century with the introduction of wastewater systems for conducting household wastes. Some of the significant worldwide activities in wastewater reclamation that have occurred since 1960 are summarized in Table 3.

Period	Location	Event
1962	La Soukra	Irrigation with reclaimed water for citrus plants and ground water recharge to reduce saltwater.
1965	Israel	Use of secondary effluent for crop irrigation.
1968	Windhoek, Namibia	Research on direct potable reuse and subsequent implementation.
1969	Wagga Wagga, Australia	Landscape irrigation of sporting fields, lawns, and cemeteries.
1977	Tel-Aviv, Israel	Dan region project- Groundwater recharge via basins. Pumped groundwater is transferred via a 100 km long conveyance system to southern Israel for unrestricted crop irrigation.
1984	Tokyo, Japan	Toilet flushing water for commercial buildings in the Shinjuku District using reclaimed water from the Ochiai wastewater treatment plant operated by the Tokyo Metropolitan Sewerage Bureau.
1988	Brighton, UK	Inauguration of the Specialist Group on Wastewater reclamation, Recycling and reuse at the 14th Biennial Conference of the International Association on Water Pollution Research and Control (currently, the International Water Association, headquartered in London ,UK).
1989	Girona, Spain	Golf course irrigation using reclaimed water from the Consorci de la Costa Brava wastewater treatment facility.
1999	Adelaide, South Australia	The Virginia Pipeline Project, the largest water reclamation. project in Australia- irrigating vegetable crops using reclaimed water from the Bolivar Wastewater Treatment Plant (120,000 m^3/d).
2002	Singapore	NEWater-reclaimed water that has undergone significant purification using microfiltration, reverse osmosis, and ultrafiltration disinfection. NEWater is used as a raw water source to supplement Singapore's water supply.
2010	Singapore	The largest wastewater treatment will be built in Jurong Singapore in June 2010

Table 3. The evolution of wastewater reclamation and reuse in the world (Lane 1990, Baird and Smith 2002).

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Bibliography

Ahn K.H., J.H.Y. Song Cha, K.G. Song, and H.Yoo (1998). *Application of tubular ceramic membrane for building wastewater reuse* (Proceeding IAWQ 19th International Conference) Vancouver, p.137.[This is a case study reporting on the application of membrane technology for wastewater reuse].

Alberti B., A. Bienati, A. Bottino, G. Cappanelli, A. Comite, F. Ferrari, and R. Firpo (2007). Hydrocarbon removal from industrial wastewater by hollow-fiber membrane bioreactors, *Desalination* 204, 24-32.[This present approaches to the study of hydrocarbon removal using membrane bioreactor system].

Angelakis A.N., N.V. Paranychianakis, and K.P. Tsagarakis (2003). Water Recycling in Mediterranean Region, *Water Sci. Technol*. 3(4), 23-28.[This presents approaches to the issues of wastewater problem in Mediterranean Region].

Asano T., F. L. Burton, H. L. Leverenz, R. Tsuchihashi, and G. Tchobanoglous. (2007). *Water Reuse: Issues, Technology and Applications*, 1570 pp, McGraw-Hill, New York, USA.[A comprehensive discussion of challenge to water treatment includes issues, engineers, and technology that considered to addressing health parameters].

Asano, T. (1998). *Wastewater reclamation and reuse*, 1528 pp, Technomic Publishing Company Inc., Pennsylvania, USA.[This discusses general topics essential to determined attempt to assemble, analyse, and review the aspects of the wastewater reclamation, recycling, and reuse in most parts of the world].

Bae T.H., I.C. Kim, and T.M. Tak (2006). Preparation and characterization of fouling-resistant TiO_2 self-assembled nanocomposite membrane, *J. Membr. Sci*. 275, 1-5. [This studies the phenomenon of TiO_2 self-assembled nanocomposite membrane to decrease the fouling problems].

Baird, R.B. and R. K. Smith (2002), *Third Century of Biochemical Oxygen Demand*, Water Environment Federation, Alexandria, VA.[A document that provides information on the environmental impact of Biochemical Oxygen Demand growth].

Baker, R.W. (2000). Membrane technology and applications, 514 pp, Mc Graw Hill, USA.[This studies comprehensive on membrane preparation, transport theory, and concentration].

Boen, D.F. and G.L. Johnson (2001). *Reverse osmosis of treated and untreated secondary sewage effluent*, 168 pp, Water Pollution Research series 17040.[A comprehensive discussion of the reverse osmosis process for sewage effluent].

Bolong, N., A.F. Ismail, M.R. Salim, D. Rana, T. Matsuura, and A.T. Muhammadi (2010). Negatively charged polyethersulfone hollow fiber nanofiltration membrane for the removal of bisphenol A from wastewater, Separation and Purification Technology 73(2), 92-99.[This studies the phenomenon of negatively charged of membrane surface in membrane process].

Bottino, A., Capanelli, G., Munari, S., and Turturro, A. (1988). High performance ultrafiltration membranes cast from LiCl doped solution, *Desalination* 68, 167-177.[This studies the effect of flat sheet membrane with addition of LiCl on dope solution].

Bourgeous, K., G. Tchobanoglous, and J. Darby (1999). *Performance evaluation of the Koch Ultrafiltration (UF) membrane system for wastewater reclamation,* Center for Environmental and Water Resources Engineering, Report No.99(2), Departement of Civil and Environmental Engineering, University of California, Davis CA.[This presents approaches to the evaluation study of the Koch Ultrafiltration membrane system for wastewater reclamation].

Bruining, W.J. (1989). A general description of flows and pressures in hollow fiber membrane modules, *Chem. Eng. Sci.* 44, 1441-1447.[This is a case study reporting on the application of hollow fiber membrane to water treatment].

Busch, J., A.Cruse, and W. Marquadt (2007). Modelling submerged hollow fiber filtration for wastewater treatment, *J. Membr. Sci*. 288, 94-111.[A comprehensive discussion of the application of submerged membrane filtration in wastewater treatment].

Cath, T.Y. (2005). Membrane contactor processes for wastewater reclamation in space II. Combined direct osmosis, osmotic distillation, and membrane distillation for treatment of metabolic wastewater, *J. Membr. Sci.* 257, 111-119.[A comprehensive discussion of the application of membrane filtration in wastewater treatment].

Chang, I.S. and A.G. Fane (2001). The effect of fibre diameter on filtration and flux distribution-relevance to submerged hollow fibre modules, *J. Membr. Sci.* 184, 221-231.[This studies the effect of characteristic of hollow fiber membrane for submerged membrane process].

Chiang, C.Y., M. J. Reddy, and P. P. Chu (2004). Nano-tube TiO_2 composite PVDF/$LiPF_6$ solid membranes, *Solid State Ionics* 175, 631-635. [This studies the effect of organic-inorganic additive LiPF6/TiO2 on PVDF composite membrane to increase the membrane performance].

Comerton, A.M., Andrews, R.C., and Bagley, D.M. (2005). Evaluation of an MBR-RO System to Produce High Quality Reuse Water: Microbial Control, DBP Formation and Nitrate, Wat. Res., 39, 3982–3990.[This presents development of RO system for water treatment].

Crozes, G.F., J.G. Jacangelo, C. Anselme, and J.M. Laine (1997). Impact of ultrafiltration operating conditions on membrane irreversible fouling, *J. Membr. Sci.* 124, 63-67.[This is a case study reporting on the effect of operating condition for membrane ultrafiltration system].

Cui, Z.F., S. Chang, and A.G. Fane (2003). The use of gas bubbling to enhance membrane process-a review, *J. Membr. Sci*. 221, 1-35.[This presents approaches to the study of effect the air bubble for membrane filtration].

Currier, J. (2008). Novel Wastewater reclamation technology meets environmental and business challenges, *J. Intel Tech.* 12, 49-58.[This is a case study reporting on the linkages of wastewater reclamation technology, environmental and business challenges].

Domerie, P. (2008). Wastewater reclamation technology links environment and business challenges, *J. Intel Tech.* 11(1), 34-42.[This studies reporting on the application of membrane technology and its benefit to business challenges].

Drinan, J.E. (2001). *Water and Wastewater Treatment*, 316 pp, CRC Press, Florida, US. [A comprehensive discussion of the water and wastewater treatment in an ecological perspective to cover the specific needs of nonengineers in water and wastewater industry].

Driscoll, T.P. (2000). *Industrial Wastewater Management Treatment and Disposal*, 231 pp, WEF Press, Virginia, USA.[This presents the management treatment and disposal for water purification].

Environmental Protection Agency (1994). *Water Quality Handbook*, 2nd ed., 238 pp, U.S. EPA 823-B-94-005a, Washington, U.S.[A comprehensive study of the conventional and advanced wastewater treatment, water and wastewater processing, and maintenance of water and wastewater facilities].

Fane, A.G., F. Wicaksana, and V. Chen (2006). Fibre movement induced by bubbling using submerged hollow fibre membranes, *J.Membr.Sci*. 271, 186-195.[This presents a comprehensive study of effect the air bubbles on submerged membrane process].

Hammer, M.J. and M.J. Hammer, Jr. (2008). Water and wastewater technology, 552 pp, 6th edition, Pearson Prentice Hall, New Jersey, Ohio.[A book that provides comprehensive coverage of the fundamental principles and current practices in water processing, water distribution, wastewater collection, wastewater treatment and water reuse].

Hermanowicz, S.W. (2005). *Sustainability in Water Resources Management: Changes in Meaning and Perceptions*, University of California Water Resources Center Archives, http://respositories.cdlib.org/wrca/wp/swr_v3.[This document provides information on water resources and its sustainability].

Hiasa, M. (2007). Direct solid-liquid separation using hollow fiber membrane in an activated sludge aeration tank, *Water Sci. Technol*., 21, 43-54.[This is a case study reporting on the application of membrane technology for advanced water treatment].

http://www.Kubota.com. Retrieved 2010-02-15.[A report that provides emerging information of Kubota about their products].

http://www.Toray industry.com. Retrieved 2010-03-03.[An information that is provided by Toray industry of their latest product].

http:www/sewage treatment/Wikipedia.com, recited (2010-02-21).[This presents approaches to treat the sewage using conventional technology and membrane technology].

International Water Management Institute (2000). *World Water Supply and Demand: 1990 to 2025*, 490 pp, IWMI Colombo, Sri Lanka.[A document that provides information on the water supply and demand in the world].

Ismail, A.F. and A.R. Hassan (2006). Formation and characterization of asymmetric nanofiltration membrane: Effect of shear rate and polymer concentration, *Journal of Membrane Science* 270(1-2) 57-72.[This presents the study of effect of shear rate on membrane structure].

Ismail, A.F. and W.J. Lau (2009). Influence of feed conditions on the rejection of salt and dye in aqueos solution by different charactheristics of hollow fiber nanofiltration membranes, *Desalination* 6 281-288.[This presents approaches to the study of nanofiltration membrane for dye solution].

Ismail, A.F., M.I. Mustaffar, and R.M. Illias (2006). Effect of dope extrusion rate on morphology and performance of hollow fiber ultrafiltration membrane, *Separation Science and Technology* 49(1) 10-19.[This studies the phenomenon of effect dope extrusion on morphology and performance of hollow fiber membrane].

Jian, K. and P. N. Pintauro (1997). Asymmetric PVDF hollow fiber membranes for organic/water pervaporation separations, *J. Membr. Sci.* 135 41-53.[This is a case study reporting on the application of hollow fiber membrane for water treatment].

Judd, S. (2005). Fouling control in submerged membrane bioreactors, *Water Sci. Technol*., 51, 6-7, 27-34.[This study reported the parameter that increase fouling resistance in submerged membrane bioreactor process].

Judd, S. and C. Judd (2006). *The Membrane Book: Principle and Applications of Membrane Bioreactors in Water and Wastewater Treatment*, 344 pp, 1st ed., Elsevier, Oxford.[This book covers all important aspects of Membrane Bioreactors in water and waste water treatment, from the fundamentals of the processes via design principles to MBR technologies].

Kalyandurg, I.B. (2003). *Study of reaction kinetics of a submerged membrane activated sludge process*, 264 pp, Ph.D Thesis, King Fahd University of Petroleum and Minerals.[A comprehensive study of the reaction kinetics parameter in submerged membrane process for refinery wastewater].

Khopkar, S.M. (2004). *Environmental Pollution Monitoring and Control*, 299 pp, New Age International, New Delhi.[This reports approaches to the study to control of environmental pollution].

Krauth, K. and K.F. Staab (1993). Pressurized bioreactor with membrane filtration for wastewater treatment, *Water Res*. 27, 405-411.[This studies the effect of pressure on membrane bioreactor for wastewater filtration].

Kurbiel, J.(1996). Implementation of the Cracow municipal wastewater reclamation system for industrial water reuse, *Desalination* 106, 183-193.[This investigates a case study of Cracow municipal wastewater reclamation].

Lane, T. J. (1990). *Handbooks of Water Treatment Plant Design, American Water Work Association (AWWA)*, section 1, p 1-6, McGraw-Hill, New York, USA.[This discusses to the principal challenge to water treatment engineering cost-effectiveness].

Lau, W.J. and A.F. Ismail (2008). Effect of structural and electrical properties of hollow fiber nanofiltration membranes on salt and dye removal under different solution properties, *Jurnal Teknologi* 49(F), 103-113.[This studies the effect of membrane structure of hollow fiber membrane on salt and dye solution].

Lau, W.J. and A.F. Ismail (2009). Effect of SPEEK content on the morphology and electrical properties of PES/SPEEK blend nanofiltration membrane, Desalination, 249(3), 996-1005.[This presents approaches to the study of nanofiltration processes].

Lau, W.J. and A.F. Ismail (2009). Theoritical studies on the morphology and electrical properties of blended PES/SPEEK nanofiltration membranes using different sulfonation degree of SPEEK, *Journal of Membrane Science* 334, 30-42.[This presents approaches to the study of hollow fiber membrane morphology].

Le-Clech,P., B. Jefferson, I.S. Chang, and S. Judd (2003). Impact of aeration, solids concentration and membrane characteristics on the hydraulic performance of a membrane bioreactor, *Journal of Membrane Science* 218, 117-129.[This presents the impact of parameter processing and membrane characteristics on the membrane bioreactor performance].

Mitchell, R. and J.D. Gu (1998). *Use of Microorganisms and Their Metabolites,* p 1-15, *AWWA M48,* American Water Works Association, Denver, CO.[This studies approaches to the study of effect of microorganisms in activated sludge processes].

Mulder, M. (1996). *Basic Principles of Membrane Technology*, 564 pp, Kluwer Academic, London.[This book discusses comprehensive to principles of membrane technology such as definition of membrane, types of membrane processes, membrane configuration, membrane composition, and membrane system components and design considerations].

Ochoa, N.A., M. Masuelli, and J. Marchese (2003). Effect of hydrophilicity on fouling of a emulsified oil wastewater with PVDF/PMMA membranes, *J.Membr. Sci*. 226, 203-211.[This studies of effect of hydrophilicity on membrane performance for oily wastewater].

Osmonics Inc. (2002). *The Filtration Spectrum*, Osmonic Inc., Minnetonka, Minnesota, USA.[A table that provides information on the filtration spectrum of membrane processess].

Porter, M.C. (1990). *Handbook of Industrial Membrane Technology*, 604 pp, Noyes Publications, Park Ridge, New Jersey, USA.[This book emphasizes the use of membrane for separations involving industrial or municipal process stream].

Rahman, M.M., and A. Malack (2006). Performance of a crossflow membrane bioreactor (CF-MBR) when treating refinery wastewater, *Desalination* 191, 16-26.

Robert, A.B. (2005). *Water Treatment Principles and Design*, Second Edition, John Willey and Sons, Inc. New Jersey, USA.

Roefer, P.S., R.E. Snyder, D.J. Rexing, and J.L. Frank (2000). Endocrine-Disrupting Chemicals in Source Water, *Journal American Water Work Association*, 92, 8. [This studies the phenomenon of disrupted chemicals in water].

Sakinah, A.M.M., A.F. Ismail, M.I. Rosli, H. Osman, A.W. Zularisam, and T. Matsuura (2008). Cyclodextrin production in hollow fiber membrane reactor system: Effect of substrate preparation, *Separation and Purification Technology* 63, 163-171.[This presents of the study membrane reactor system].

Savaria, F., C. Zwiener, and F.H. Frimmel (2006). Interactions between membrane surface, dissolved organic substances and ions submerged membrane filtration, *Desalination* 192, 280-287.[This studies of effect of membrane structure on membrane performance for wastewater treatment].

Schaefer, A.I., A.G. Fane, and T.D. Waite (2000). Fouling effects on rejection in the membrane filtration of natural waters, *Desalination*, 131, 215-231.[This studies of effect of membrane surface on membrane performance for natural wastewater].

Scholz, W. and W. Fuchs (2000). Treatment of oil-contaminated wastewater in a membrane bioreactor, *Water Res.*, 34(14): 3621-3629.[This presents approaches to the study of oily wastewater treatment].

Sikdar, S.K. (2005), Science of Sustainability, *Clean Technology Environment Polymer*, 7, 1, 1-2. [This presents approaches to the study of water sustainability].

Sourirajan, S. and T. Matsuura (1985). *Reverse Osmosis and Ultrafiltration: A review*, 508 pp, ACS Symposium Series 281, American Chemical Society, Washington, D.C.[A comprehensive discussion of the reverse osmosis and ultrafiltration membrane processess].

Sudak, R.G., W. Dunivin, and M. G. Rigby (1990). *Municipal wastewater reclamation and reverse osmosis* (Proceedings of the national water supply improvement association), p.225, Biennial Conference, Florida.[This presents approaches to the study of municipal wastewater reclamation using conventional method and reverse osmosis].

Taylor J.S. and E.P. Jacobs (1996). *Reverse Osmosis and Nanofiltration, Water Treatment Membrane Processes*, p. 183-195, American Water Works Association, McGraw Hill, New York, USA.[This studies the feasibility of treating the effluent from the wastewater treatment plant（WTP）of an industrial park for reuse using reverse osmosis (RO) and nanofiltration (NF) due to development and improvement of membrane technologies].

Tchobanoglous, G. (2003). The Strategic Importance of Decentralized Wastewater Management in the Twenty-First Century (Proceedings of the Water Reuse & Desalination Conference, Suntec, Singapore, 2003), Topsfield, MA: International Desalination Association. [A comprehensive discussion of the wastewater and water treatment and reuse].

Tzahi Y.C., D. Adams, and A.E. Childress (2004). Membrane process for wastewater reclamation: Combined direct osmosis, osmotic distillation, and membrane distillation for treatment metabolic wastewater, *J. Membr. Sci*. 257, 111-119. [This studies of application in membrane processes for wastewater reclamation].

Viero,A.F., Sant'Anna Jr,G.L., and Nobrega, R. (2007). The use of polyethermide hollow fibres in a submerged membrane bioreactor operating with air backwashing, *J. Membr. Sci.* 302, 127-135.[This studies of effect operating parameter of polyethermide hollow fiber membrane in submerged membrane bioreactor].

Wang, Y.J. and D. J. Kim, (2007). Crystallinity, morphology, mechanical properties and conductivity study of in situ formed PVDF/$LiClO_4$/ TiO_2 nanocomposite polymer electrolytes, *Electrochimika Acta* 2, 3181-3189.[This studies of effect of entrapment of inorganic organic additives on PVDF membrane structure and morphology].

Yuliwati, E. and A.F. Ismail (2010). *PVDF-TiO_2 submerged hollow fiber membrane in refinery produced wastewater treatment* (Proceeding IWAY2010 1st International Conference, Kuala Lumpur, 2010), p.126, [This studies of effect of hydrophilicity on membrane performance for refinery produced wastewater].

Zhang, S. Ji, X. Gao, and Z. Liu (2008). Adsorptive fouling of extracellular polymeric substances with polymeric ultrafiltration membranes, *J. Membr. Sci.* 309, 28-35.[This studies the phenomenon of fouling on membrane process].

Zularisam, A. W., A.F. Ismail, and M.R. Salim (2006). Behavior of natural organic matter (NOM) in membrane filtration for surface water treatment: A review, Desalination 194(1-3), 211-231.[This studies the behavior of natural organic matter (NOM) in membrane process].

Zularisam, A. W., A.F. Ismail, M.R. Salim, and Mimi Sakinah (2007). Roles of natural organic matter (NOM) fractions on fouling characteristics and flux recovery of ultrafiltration membrane, *Desalination* 212, 191-208.[This presents approaches to the study of effects the natural organic matter on membrane performance using submerged membrane process].

Zularisam, A. W., A.F. Ismail, M.R. Salim, Mimi Sakinah, and O. Hiroaki (2007). Fabrication fouling and foulant analyses of asymmetric polysulfone (PES) ultrafiltration membrane fouled natural organic matter (NOM) sources waters, Journal of Membrane Science, 299(1-2), 97-113. [This presents approaches to the study of fouling fabrication and foulant analyses on membrane surface].

Biographical Sketches

Ahmad Fauzi Ismail (B.Sc Petroleum E., M.Sc Chem. E. Universiti Teknologi Malaysia, Ph.D. Chem. and Process E. University of Strathclyde, Glasgow, Scotland, U.K.) is Professor of Membrane Technology in Faculty of Petroleum Engineering and Renewable Energy at Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia and Head of Advanced Membrane Technology Research Center (AMTEC). Currently he is the Dean of Research of Material and Manufacturing Research Alliance. He hold a US Patent, UK Patent and eleven Malaysian Patents have been filed from his research works.

Professor Ismail has a particular interest in gas separation processes especially CO_2 removal from natural gas, O_2/N_2 separation, H_2 recovery, H_2/N_2 separation using polymer and inorganic materials. In addition, he also has a special interest in developing reverse osmosis, nanofiltration and ultrafiltration membrane for water and wastewater treatment and for biotechnology application. His recent research includes the development of composite materials from carbon fibers and carbon nanostructure for energy storage. He has more than 260 publications in academic journals, conference proceedings and book chapters. In the year 2000, he won the ASEAN Young Scientist and Technologist Award and Malaysia Young Scientist Award. He has also received more than 60 awards of which 24 are at the international level. He has also been awarded the first Prominent Researcher of UTM in 2008. He has been appointed as Editor-in-Chief of Applied Membrane Science and Technology, an international journal published by UTM press. He has also been appointed as the Editorial Board Member for Desalination journal, Membrane Water Treatment Journal and Journal of Rubber Research. Recently, he received the *Prime Minister Initiatives Award (PMI2) for Strategic Alliances and Partnership Project*, a research grant for two years in collaboration with Imperial College, London, sponsored by The British Council. At present he is supervising 23 PhD students and 12 MSc students. Recently, he was awarded the Grand Prize Winner for the National Intellectual Property in the Patent Category and won the National Innovation Award in the Waste to Wealth Category (2009).

Erna Yuliwati (B. Chem.E., M.Sc Chem.E. University of Sriwijaya Indonesia, Chemical Technologie Fakultaet (Bestaetigung), Fachhochschule Darmstadt, Germany) is a PhD candidate of Chemical Engineering at Universiti Teknologi Malaysia (UTM). Before joining the Advanced Membrane Technology Research Centre (AMTEC), UTM in 2009, she worked as a lecturer for University of Bina Darma and Director of Research and Community Development Centre in University of Bina Darma, She also served as researcher in Research and Development Centre, South Sumatra Province, Indonesia. She has worked as a consultant on process development to Indonesia Popular Governance Institute, Bandung, Indonesia and Inovasi Institute, Palembang, Indonesia which taken part in a Community Development and Populist Economic Improvement. She has participated in Asia and Europe Peoples Forum (AEPF) in Finland (2006) and China (2008) to support the development of technological innovations which improved the considerations for sustainability of energy and resources usage and environmental pollution.