

Prospect and Challenges of Tight Ultrafiltration Membrane in Drinking Water Treatment

P T P Aryanti¹, A N Hakim², S Widodo^{2,3}, I N Widiasta⁴, I G Wenten^{2,*}

¹Chemical Eng. Dept., Jenderal Achmad Yani University, Jl. Terusan Jend. Sudirman PO BOX 148, Cimahi, Indonesia.

²Department of Chemical Engineering, Institut Teknologi Bandung, Jl. Ganesha 10, Bandung 40132, Indonesia.

³PPPTMGB LEMIGAS, Balitbang KESDM, Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, Jakarta, 12230, Indonesia.

⁴Chemical Engineering Department, Diponegoro University, Jl. Prof Sudarto-Tembalang, Semarang 50239, Indonesia.

*Corresponding author: igw@che.itb.ac.id

Abstract. Ultrafiltration (UF) membrane for drinking water treatment has been consistently modified to improve the selectivity towards trace organic compounds (TrOCs) and maintain the flux stability for long-term application. Currently, the tight UF membrane has been developed to answer the challenges of conventional UF membranes. With small pore size (300 - 5000 Da), the tight UF showed higher TrOCs rejection and lower irreversible fouling than the conventional UF membranes. Two methods have been proposed to fabricate the low molecular weight cut off (low-MWCO) UF membranes, i.e. blending membrane solution with fillers (nanoparticles or volatile solvent) and modifying membrane surface layer by chemical or plasma grafting method. Low water flux and high operating pressure are some challenges to be solved during the application of the tight UF membrane. Hence, the development of tight UF membrane with low-MWCO pore size has focused on improving flux while maintaining high selectivity. In this paper, the development and prospect of tight UF membrane will be reviewed. Challenges during the application of low-MWCO UF membrane for water treatment and methods to solve the challenges will be discussed.

Keywords: drinking water, high selectivity, low-MWCO, trace organic, ultrafiltration.

1. Introduction

In drinking water treatment, pressure driven membrane technologies achieved extraordinary levels of process intensification, substantially decreasing the equipment-size/production-capacity ratio, energy consumption, and waste production, which result in lower cost and sustainable technical solutions [1- 3]. In spite the advantages, the application of pressure driven membrane in water treatment is limited by fouling phenomenon, which reduces the production efficiency [4-8]. Details of the theoretical background of the pressure-driven membrane processes including strategies to prevent and mitigate membrane fouling have been reported in several literature [9-16]. Reverse osmosis (RO) is the most used membranes in surface water treatment and desalination to produce fresh (pure) water with low content of soluble organics and ions [17-19]. However, the demineralized water by RO has not been recommended as drinking water for long-term consumption related to the World Health Organization



(WHO) regulation [20]. The possible health consequences of low mineral content water consumption have been discussed in the literature [21, 22]. Hence, remineralization of NF and RO water product to reduce the water corrosivity is required before the water is distributed to the customer [23]. The standard for drinking water quality in terms of total dissolved solids (TDS) and mineral content has been summarized in the WHO guideline [23-25]. UF is an attractive alternative in water and drinking water treatment, which exhibits some advantages compared to NF and RO, i.e. lower investment cost, higher permeate flux, and lower energy consumption. From an economic point of view, the installation of UF membranes in water treatment plant may significantly reduce the operating cost by eliminating coagulation, flocculation, and sedimentation processes.

The UF membranes are generally characterized by their pore size between 0,01 μm (1 nm) – 0,1 μm (100 nm) or its molecular weight cut-off (MWCO) between 10,000 - 100,000 Dalton (Da) [25]. Due to its small pore size, the UF membrane provides an effective barrier for suspended particles, colloids, and pathogens while keeping the mineral content in water intake. Up to this time, the modification of UF membranes is mostly focused on improving the hydrophilicity, to reduce energy consumption and enhance productivity [26-30] and enhance an anti-fouling property of the membrane to maintain the membrane flux for long-term use [31]. Numerous review and research studies related to the UF membranes for water and drinking treatment have been published, as shown in Figure 1 [32- 38]. Simultaneously, development of UF membranes with innovative modules is also growing significantly to fulfill the requirement of fresh or drinkable water [39-42]. The development is not only for industrial and urban areas, but also for a rural and remote area that have inadequate sanitation, poor hygiene habits, and lack of adequate quantities of water for hygiene [43-46].

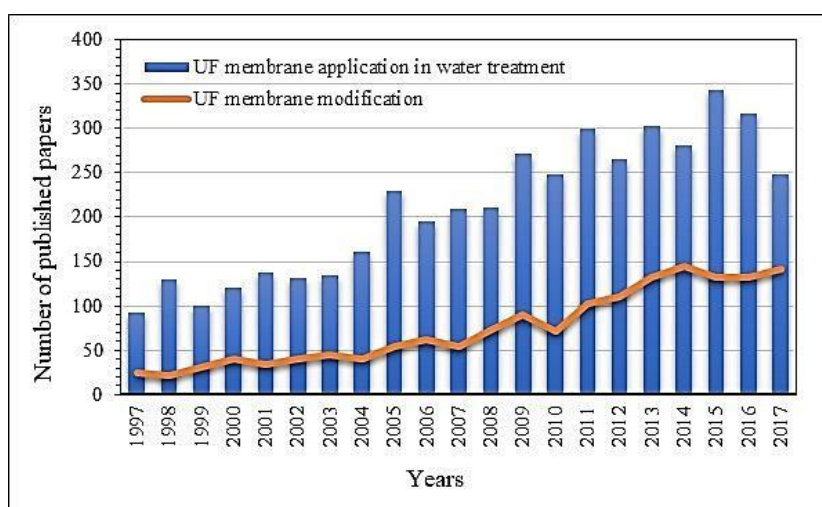


Figure 1. Number of publication related to UF membrane application in water treatment indexed by Scopus (TITLE+ABS+KEY: ultrafiltration membrane and water treatment).

Beside intrinsic fouling phenomenon, another limitation of UF membrane in water treatment, particularly for drinking water, is low rejection against soluble contaminants (up to 50%), such as trace organic compounds (TrOCs) with an approximate molecular weight below 1000 Da. The TrOCs, such as endocrine disrupting compounds (EDCs) and pharmaceuticals or personal care products (PPCPs), have been identified as harmful pollutants in drinking water treatment since they are suspected to be carcinogenic [47]. Tight UF membranes have been developed to overcome the limitation in conventional UF membranes. This membrane has a tight structure in the skin layer, with pore sizes between 300 and 5000 Da [48-52]. Due to its tight skin layer, the UF membrane has a high rejection against soluble compounds in water, such as humic substances and dyes [53, 54]. Up to this time, there exists little literature that discusses the tight UF membrane and its application for water treatment. In this paper, the low-MWCO UF membrane will be reviewed comprehensively including

the state of the art and preparation method. In addition, challenges during the application of low- MWCO UF membrane for water treatment and methods to solve the challenges will be discussed.

2. The Application of Tight UF Membrane in Water Treatment

Several studies have been conducted to investigate the performance of tight UF membranes when it was applied in water treatment. One of the studies was conducted by Kramer et al. [54]. A tight UF membrane, with a pore size of 3000 Da, was used as pre-treatment of RO membrane to produce demineralized water from raw municipal sewage. It was found that the tight UF has an ability to reject chemical oxygen demand (COD) by 80%. Lin et al. [55] investigated the selectivity of a tight UF membrane, with a pore size of 4700 Da, to separate mixtures of dyes and Na₂SO₄. The tight UF membrane showed high rejection of dyes up to 98%. Similar research was carried out by Ma et al. [56], where the tight UF was used to separate dyes and mixed salts (both NaCl/Na₂SO₄). High rejection of dyes was also achieved (>98%). The pure water permeability of tight-UF membrane was found at least 6 times that of NF membrane. These results showed that the tight UF membrane can be used as an alternative to NF membranes.

Efligenir et al. [57] used two types of UF tight membrane (1000 Da), i.e. flat-sheet polyamide and TiO₂ tubular ceramic membrane, to remove metal salts from industrial discharge water, and then compared the performance of two membranes. They found that the TiO₂ ceramic membrane showed higher rejection of some metal ions, i.e. above 80% at operating pressure of 8 bar, while the polyamide membrane rejection was only 40%. It suggested that the negative surface charge of TiO₂ ceramic membrane played an important role to the metal ion rejection. Shang et al. [58] also used TiO₂ tight ceramic UF membrane (3000 Da) as pre-treatment of RO membrane to remove phosphate in water. They investigated the influence of membrane charge on the separation efficiency of phosphate by regulating the feed water condition, such as pH and salt concentration. The results pointed out that the ceramic membrane was more negatively charged in higher pH condition, which resulted in higher rejection of phosphate. Almost 87% rejection of phosphate can be achieved at pH 8.5. Meanwhile, the presence of Na⁺ and Ca²⁺ ions in solution decreased the zeta potential of the membrane and led to the increase of natural organic matter (NOM) or effluent organic matter (EFOM) on the membrane surface [59]. The phosphate rejection was found to be correlated to the zeta potential of the organics in the feed water. The application of tight UF in water treatment is summarized in Table 1. Due to its high selectivity at low energy consumption as well as low irreversible fouling, certainly, the tight UF membrane can be considered as a future drinking water treatment technology.

Table 1. The applications of tight UF membranes in water treatment

Membrane material	UF pore size	Application	Operating condition	Results	Ref.
Polysulfone (PSf)	-	Humic substance removal in peat water	Operating pressure: 1 bar	Humic rejection: >80%; Flux: 126 LMH; Low irreversible fouling	[52]
Ceramic membrane	3000 Da	Sewage water treatment	Operating temp.: 20°C Operating pressure: 8 bar	Organic matter rejection: 81%	[54]
Polyethersulfone (PES)	4700 Da	N ₂ SO ₄ /dye separation	Operating temp.: 25 °C cross-flow rate : 60 L/h process mode: filtration-diafiltration Operating pressure: 4 bar	Na ₂ SO ₄ rejection: >98%	[55]
Ceramic Membrane (TiO ₂ /ZrO ₂ active layer)	8800 Da	Separation of dyes and mixed salts (NaCl/Na ₂ SO ₄)	Flow rate: 3 m/s at 25°C Operating pressure: 2 bar	Na ₂ SO ₄ rejection: >98% NaCl rejection < 10%	[56]
Ceramic membrane (TiO ₂)	3000 Da	Separation of phosphate	pH of solution: 6 – 8.5	87% of phosphate rejection at pH 8.5	[58]
Regenerated cellulose acetate (RC)	5000 Da	2,4,6-trichloroanisole (TCA) removal	Cross flow rate: 0,7 ml/min Operating pressure: 4 bar	TCA rejection: > 80%	[60]
Charge ceramic membrane	3000 Da	Phosphate removal during WWTP secondary effluent	pH 7.0 ± 0.5 cross-flow velocity: 1 m/s flux: 30 Lm-2h-1	Phosphate rejection: 62%	[59]
Ag-doped TiO ₂ /Ti composite membrane	3000 Da	Dye removal (chlorazol fast pink, chlorazol black, and titan yellow)	Operating pressure: 1-7 bar Operating temp.: 25°C	Dye rejection: 99%	[61]
Modified poly(vinyl butyral) (PVB) hollow fiber membranes with carbon nanotubes (CNTs)	-	Humic substance removal	-	Humic substance rejection: >90%	[62]

3. Tight UF Membrane Preparation

A few studies have been focused on the tight UF membrane preparation techniques, including the dispersing fillers (polymeric or inorganic) in membrane structure [63,64] and membrane surface modifications by chemical grafting or pore-filling method [65–67]. Among these methods, blending membrane materials with hydrophilic and anti-fouling nanoparticles has attracted much attention in tight UF membrane manufacturing along with refusing fouling from the membrane surface [68–70]. Another method has been proposed by filling the membrane pore with a high cross-link polymer through in-situ polymerization [71,72] or with nanoparticles by vacuum filtration [73]. In the following subchapter, the preparation methods of tight UF membrane will be discussed.

3.1. Tight UF polymeric membrane preparation by dispersing fillers in membrane structure

There are two methods to disperse the fillers in membrane structure, namely ex-situ and in-situ method. In ex-situ method, the fillers are dispersed by blending into the membrane solution, while in in-situ method, the fillers are directly generated in membrane solution through a chemical reaction. Blending polymer solution with hydrophilic or anti-fouling additives are widely used in the manufacture and modification of membranes used in UF membrane modification due to its simple and inexpensive method. The frequent additives used in membrane modification are hydrophilic polymer (e.g. polyvinyl pyrrolidone or PVP and polyethylene glycol or PEG), organic compounds (e.g. glycerol, alcohol), inorganic salts (e.g. LiNO_3), inorganic compound (e.g. zeolite, TiO_2 , Ag), water, and recently modified polymeric additive (e.g. sulfonated polyether ether ketone or SPEEK and PVP- co-styrene). In tight UF membrane preparation, some of these additives have been used and will be discussed in this sub-chapter.

Sadrzadeh et al. [74] manufactured UF membrane with a pore size of 2000 Da by blending 15%wt of PES and 5% wt of PVP (1300 Da). Further addition of PVP to 10%wt reduced the membrane pore size to 1000 Da and changed the membrane morphology from finger type to sponge type. Aryanti et al. [75] prepared a low-MWCO UF membrane, which had a high rejection to humic substances (up to 80%). They mixed PSf solution with acetone to obtain tight surface layer and PEG400 to increase membrane hydrophilicity. The rapid loss of acetone from the membrane solution lead to a higher polymer concentration in the membrane skin layer and produced tight pore structures [76]. As shown in Figure 2, the presence of acetone in membrane solution improved the humic substance rejection [77]. Furthermore, a tight skin layer of the membrane weakens the interaction between organic matters and the membrane surface, which is easily cleaned by flushing method and contribute to higher flux recovery ratio (FRR) [52].

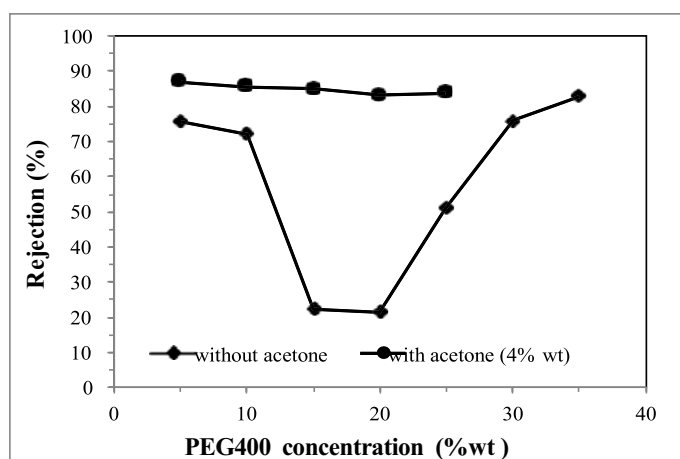


Figure 2. Effect of acetone concentration to humic substances removal [77].

Recently, blending polymer solution with inorganic nanoparticles becomes a choice of numerous researchers to produce a smaller membrane pore size with a good pore distribution along the thickness of UF membrane. TiO_2 has been widely used as an additive due to its properties and good compatibility with organic solvent during the preparation of UF membrane. It has been reported that composite UF membrane with TiO_2 is able to provide high rejection of low MWCO organic matter and good anti-fouling performance. Hamid et al. [78] found that polysulfone (PSf)/ TiO_2 composite membrane was able to perform up to 90% rejection of low molecular humic acid. However, the pore size of the resulted membrane was beyond the pore range of Tight UF. Leo et al. [79] found that almost 80% permeate flux can be maintained during filtration process of humic solution, due to the presence of zeolite in membrane structure. Another hydrophilic nanoparticles, such as ZrO_2 [80], SiO_2 [81], zeolite [82], ZnO [83, 84], and Ag [85, 86], are also considered as an alternative modifier to enhance the performances of UF membranes [79]. By increasing the nanoparticle additive concentration, the smaller finger-like pore is formed due to the exchange rate between solvent and

nonsolvent has been delayed thus resulted in a tight pore structure and higher rejection of foulants. Kotte et al. [72] prepared a tight PVDF UF membrane by in-situ generation of crosslinked PEI micro/nanoparticle (with diameters ranging from 400 nm to 3 μ m) in membrane casting solution using epichlorohydrin as crosslinker.

3.2. Surface modification of porous membrane by chemical reaction

Pore-filling method by chemical reaction is another strategy to produce a tight structure on the membrane surface (Figure 3). This method has been used in commercial membrane fabrication to modify the characteristic of membrane or covers the defective pore in membrane surfaces structure [87, 88]. A porous membrane support is immersed in a polymer solution containing other type of polymer or particles. Further thermal treatment is performed to form cross-link structure and then dried at room temperature until all solvents are evaporated. The filled membrane is immersed in a solution to extract the unwanted component from the surface structure. Lan et al. [71] filled polyvinylidene fluoride (PVDF) microfiltration membranes with phenolic resins (PRs)/block copolymers (BCPs). They dipped the PVDF membrane in a homogenous solution containing resol and F127 polymer. The coating membrane was heated to cross-link the resol and generate thermosetting PRs, while F127 was dispersed in PRs structure. The pore-filled membrane was immersed in an acid solution (H_2SO_4) to remove the F127, thus a mesopores surface layer was formed with a pore size of 2350 Da.

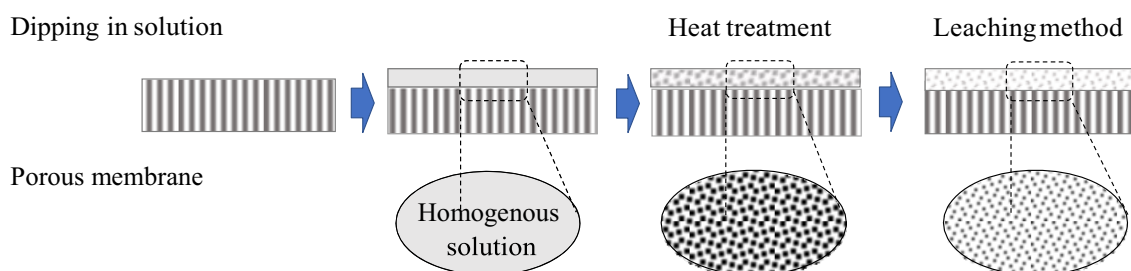


Figure 3. Schematic illustration of surface modification of porous membrane by pore-filling method.

UV-initiated graft copolymerization of poly(ethylene glycol) methacrylate (PEGMA) onto a commercial tight UF PES membranes has been performed for humic acid removal [89]. Smaller membrane pore size was produced when the energy of UV irradiation was between 5 to 9 J/cm². Further increase of UV irradiation energy resulted in a degradation of membrane pore leading to a higher membrane pore size. Another method was proposed by Chen et al. [90] to modify the surface of α -alumina UF by TiO₂ nanoparticle doping sol-gel method. The resulted UF membrane had a pore size with pore size approaching the tight UF range. Several techniques for tight UF preparations is summarized in Table 2.

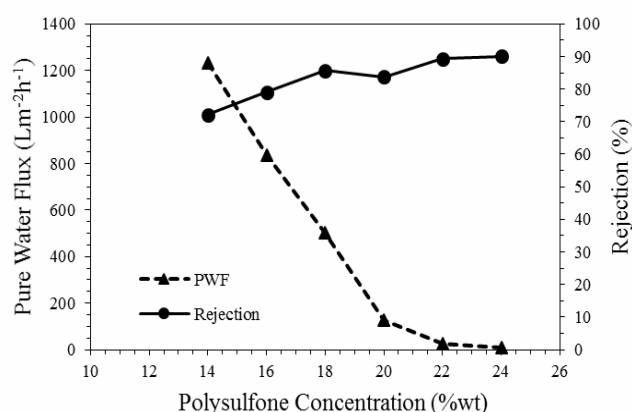
4. Challenges of Tight UF Membrane for Drinking Water Treatment

4.1. Trade-off between selectivity and permeability.

The most problem in tight UF membrane fabrication is trade-off between selectivity and permeability. These tight UF membranes had too low permeability and higher operating pressures than conventional UF membranes. Ariono et al. [65] found that higher and tighter of membrane pore size was obtained when the polymer concentration was increased, while the permeability was sharply reduced (Figure 4). The increase of polymer concentration increased the viscosity of the membrane solution, which inhibited the growth of membrane pore and reduced the pure water flux. In contrast, the tight membrane skin structure increased the membrane rejection. Further developments are continued to improve the membrane permeability while retaining tight pores [91].

Table 2. Several techniques in tight UF membrane preparation.

Modification Techniques	Methods	Membrane pore size	References
Blending	Blending polyethersulfone with PVP (1300 Da)	2000 Da	[74]
	Blending polysulfone with PEG400 and acetone	0.01 μm or 10 nm	[75]
In-situ generation of fillers	In-situ generation of crosslinked PEI in PVDF membrane structure	-	[72]
Dip-coating followed by leaching method	Supported PVDF filled with resin/polymer solution and followed by acid treatment using H_2SO_4 solution	2350 ± 200	[71]
Nanoparticle doping sol-gel method	α -alumina microfiltration filled with TiO_2 nanoparticle (average particle size: 25 nm)	14.700	[90]
UV-initiated graft copolymerization	Graft copolymerization of poly(ethylene glycol) methacrylate (PEGMA) onto a commercial tight UF PES membranes.	4 – 10	[89]

**Figure 4.** Trade-off between selectivity and permeability during tight UF membrane preparation [64].

4.2. Fouling of organic matter during drinking water treatment

Fouling phenomena have hindered the application of tight UF polymeric membranes for the proposed one-step drinking water disinfection. Although negatively charged tight UF membranes have shown some fouling resistance to colloids and humic materials, these membranes are particularly susceptible to chemical degradation due to chlorine and another oxidant attack. Therefore, developments of commercially viable fouling resistant polymeric membranes have been conducted to achieve one-step disinfection without the need for chemical pretreatment. Several techniques to produce anti-fouling UF membranes have been proposed, from passive anti-fouling to active anti-fouling [91-92]. The passive anti-fouling strategies are developed by manipulating the physicochemical or topological structure of the membrane surface to reduce the interaction between foulant and the membrane surface. Introducing hydrophilic polymers (for examples: PEG-based, PVP-based, and zwitterionic) through hydrogen bonding or ionic solvation is considered as an effective method to prevent the adsorption of foulants on the membrane surface[93,94].

In addition to the hydrophilic polymers, some anti-microbial inorganic nanoparticles (NPs) are also used to avoid the adsorption of foulants to the membrane surface, such as metals (silver/Ag) and metal oxides (TiO_2 , SiO_2 , Fe_3O_4 , and ZnO). Among these NPs, Ag NPs are commonly used as anti-fouling agent in the membrane structure due to its ability to disrupt the cell of bacteria and kill the bacteria when attached on the membrane surface. When using NPs in UF membrane modification for drinking water treatment, the most problems that need to be addressed is the release of NPs from the membrane structure to the environment. Up to this time, a few strategies have been proposed to improve the entrapment of NPs in membrane structure, such as PVP or PEG addition into the membrane solution during membrane preparation and modification of the membrane surface before depositing silver on the surface.

5. Conclusions

Some techniques for preparation of tight UF membrane have been developed to answer the challenges of conventional UF membranes. The tight UF membrane which has a tight structure in the skin layer showed a high rejection towards the TrOCs and low-irreversible fouling compared to the conventional UF membranes. In some cases, the tight UF membrane can be used as an alternative to NF membranes.

Two methods have been proposed to fabricate the low-MWCO UF membranes, i.e. blending nanoparticles or volatile solvent into membrane solution and modifying membrane surface by chemical or plasma grafting method. Low water flux and high operating pressure are challenges of the tight UF membrane application in water treatment which need to be solved. Hence, the development of tight UF membrane has focused on improving flux while maintaining high selectivity.

Introducing hydrophilic polymers or anti-fouling agents onto the membrane surface is considered as an effective method to improve the membrane permeability as well as to avoid the adsorption of foulants to the membrane surface. Recently, nanoparticles (NPs) with anti-microbial properties are increasingly used in membrane modification to reduce fouling formation on the membrane surface. When using the nanoparticles in UF membrane modification for drinking water treatment, the main problem is the release of NPs from the membrane structure to the environment. Therefore, a few strategies should be considered to improve the entrapment of NPs in membrane structure.

6. References

- [1] Sirkar KK, Fane AG, Wang R, Wickramasinghe SR. 2015 Process intensification with selected membrane processes *Chemical Engineering and Processing: Process Intensification* **87**:16- 25
- [2] Himma NF, Prasetya N, Anisah S, Wenten IG 2018 Superhydrophobic membrane: progress in preparation and its separation properties *Reviews in Chemical Engineering* 20170030
- [3] Wenten IG, Khoiruddin K, Hakim AN, Himma NF 2017 The Bubble Gas Transport Method *Part 3: Physical and Chemical Characterization Methods for Membrane Characterization, (Membrane Characterization)* ed Nidal Hilal et.al., (Amsterdam: Elsevier) Chapter 11 pp. 199-218
- [4] Du X, Wang Y, Leslie G, Li G, Liang H 2016 Shear stress in a pressure-driven membrane system and its impact on membrane fouling from a hydrodynamic condition perspective: a review *J Chem Technol Biotechnol* **92**(3) 463-478
- [5] Wenten IG, Ariono D, Purwasasmita M, Khoirudin 2017 Integrated processes for desalination and salt production: A mini-review *AIP Conference Proceedings* **1818**(1) p. 020065
- [6] Wardani AK, Hakim AN, Khoiruddin, Destifen W, Goenawan A, Wenten IG 2017 Study on the influence of applied voltage and feed concentration on the performance of electrodeionization in nickel recovery from electroplating wastewater. *AIP Conference Proceedings* **1805**(1) p. 030004

- [7] Wardani AK, Hakim AN, Khoiruddin, Wenten IG 2017 Combined ultrafiltration-electrodeionization technique for production of high purity water *Water Science and Technology* **75**(12) 2891-9
- [8] Khoiruddin, Aryanti PTP, Hakim AN, Wenten IG 2017 The role of ion-exchange membrane in energy conversion. *AIP Conference Proceedings* **1840**(1) 090006
- [9] Basile A, Cassano A, Rastogi NK 2015 Advances in Membrane Technologies for Water Treatment: Materials, Processes and Applications in *Woodhead Publishing Series in Energy* Elsevier
- [10] Bottino A, Capannelli G, Comite A, Ferrari F, Firpo R, Venzano S 2009 Membrane technologies for water treatment and agroindustrial sectors *Comptes Rendus Chimie* **12**(8):882-8
- [11] Peters T. 2010 Membrane Technology for Water Treatment *Chemical Engineering & Technology* **33**(8) 1233-40
- [12] Quist-Jensen C, Macedonio F, Drioli E 2015 Membrane technology for water production in agriculture: Desalination and wastewater reuse *Desalination* **364** 17-32
- [13] Subramani A, Jacangelo JG 2015 Emerging desalination technologies for water treatment: a critical review. *Water Research* **75** 164-87
- [14] Shi X, Tal G, Hankins NP, Gitis V 2014 Fouling and cleaning of ultrafiltration membranes: a review *Journal of Water Process Engineering* **1** 121-38
- [15] Aryanti PTP, Sianipar M, Zunita M, Wenten IG 2017 Modified membrane with antibacterial properties *Membrane Water Treatment* **8**(5) 463-81
- [16] Sianipar M, Kim SH, Khoiruddin, Iskandar F, Wenten IG 2017 Functionalized carbon nanotube (CNT) membrane: progress and challenges *RSC Advances* **7**(81) 51175-98
- [17] Yüksel S, Kabay N, Yüksel M. 2013 Removal of bisphenol A (BPA) from water by various nanofiltration (NF) and reverse osmosis (RO) membranes *Journal of hazardous materials* **263** 307-10
- [18] Al-Rifai JH, Khabbaz H, Schäfer AI. 2011 Removal of pharmaceuticals and endocrine disrupting compounds in a water recycling process using reverse osmosis systems *Separation and Purification Technology* **77**(1) 60-7
- [19] Wenten IG, Khoiruddin 2016 Reverse osmosis applications: Prospect and challenges *Desalination* **391** 112-25
- [20] Kozisek F 2005 Health risks from drinking demineralised water *Nutrients in Drinking Water* (Geneva : Sanitation and Health Protection and the Human Environment, World Health Organization) p.148-63
- [21] Verma KC, Kushwaha AS 2014 Demineralization of drinking water: Is it prudent? *Medical Journal Armed Forces India* **70**(4) 377-9
- [22] Donohue J.M., Abernathy C.O., Lassovszky P. and Hallberg G 2005 The contribution of drinking water to total daily dietary intakes of selected trace mineral nutrients in the United States. In *Nutrients in drinking water* (World Health Organization, Ed. Geneva) pp 75-91
- [23] Avni N, Eben-Chaime M, Oron G 2013 Optimizing desalinated sea water blending with other sources to meet magnesium requirements for potable and irrigation waters *Water Research* **47**(7) 2164-76
- [24] World Health Organization. Nutrients in drinking water. 2005. http://www.who.int/water_sanitation_health/dwq/nutrientsindw.pdf
- [25] Loo S-L, Fane AG, Krantz WB, Lim T-T 2012 Emergency water supply: A review of potential technologies and selection criteria *Water research* **46**(10) 3125-51
- [26] Zeman LJ, Zydney AL 1996 Microfiltration and ultrafiltration: principles and applications (New York : Dekker)
- [27] Li D, Hu J, Low Z-X, Zhong Z, Wang Y 2016 Hydrophilic ePTFE membranes with highly enhanced water permeability and improved efficiency for multipollutant control *Industrial & Engineering Chemistry Research* **55**(10)2806-12

- [28] Liang S, Kang Y, Tiraferri A, Giannelis EP, Huang X, Elimelech M 2013 Highly hydrophilic polyvinylidene fluoride (PVDF) ultrafiltration membranes via postfabrication grafting of surface-tailored silica nanoparticles *ACS applied materials & interfaces* **5**(14):6694-703
- [29] Aryanti PTP, Yustiana R, Purnama R, Wenten IG 2015 Performance and characterization of PEG400 modified PVC ultrafiltration membrane *Membrane Water Treatment* **6**(5) 379-92
- [30] Fujioka T, Khan SJ, McDonald JA, Nghiem LD 2015 Validating the rejection of trace organic chemicals by reverse osmosis membranes using a pilot-scale system *Desalination* **358** 18-26
- [31] Geng Z, Yang X, Boo C, Zhu S, Lu Y, Fan W, et al. 2017 Self-cleaning anti-fouling hybrid ultrafiltration membranes via side chain grafting of poly (aryl ether sulfone) and titanium dioxide *Journal of Membrane Science* **529** 1-10
- [32] Van der Bruggen B 2009 Chemical modification of polyethersulfone nanofiltration membranes: a review *Journal of Applied Polymer Science* **114**(1) 630-42
- [33] Miller D, Dreyer D, Bielawski C, Paul D, Freeman B 2016 Surface Modification of Water Purification Membranes: a Review *Angewandte Chemie International Edition* **56**(17) 4662-4711
- [34] Lalia BS, Kochkodan V, Hashaiekh R, Hilal N 2013 A review on membrane fabrication: Structure, properties and performance relationship *Desalination* **326** 77-95
- [35] Lau WJ, Ismail AF, Matsuura T, Nazri NA, Yuliwati E 2015 Advanced Materials in Ultrafiltration and Nanofiltration Membranes *Handbook of Membrane Separations: Chemical, Pharmaceutical, Food and Biotechnological Applications* (New York: CRC Press) p. 7-34
- [36] Jhaveri JH, Murthy Z 2016 A comprehensive review on anti-fouling nanocomposite membranes for pressure driven membrane separation processes *Desalination* **379** 137-54
- [37] Kumar RS, Arthanareeswaran G, Paul D, Kweon JH 2015 Modification methods of polyethersulfone membranes for minimizing fouling–Review *Membrane Water Treatment* **6**(4) 323-37
- [38] Kaner P, Rubakh E, Kim DH, Asatekin A 2017 Zwitterion-containing polymer additives for fouling resistant ultrafiltration membranes *Journal of Membrane Science* **533** 141-59
- [39] Bu-Rashid KA, Czolkoss W 2007 Pilot Tests of Multibore UF Membrane at Addur SWRO Desalination Plant, Bahrain *Desalination* **203**(1) 229-42
- [40] Heijnen M, Winkler R, Berg P 2012 Optimisation of the geometry of a polymeric Multibore® ultrafiltration membrane and its operational advantages over standard single bore fibres *Desalination and Water Treatment* **42**(1-3) 24-9
- [41] Kabay N, Köseoğlu P, Yavuz E, Yüksel Ü, Yüksel M 2013 An innovative integrated system for boron removal from geothermal water using RO process and ion exchange-ultrafiltration hybrid method *Desalination* **316** 1-7
- [42] Zhenjiang L 2010 The innovation of seven-channel ultrafiltration hollow fiber membranes made from PVC alloy [J]. *Membrane Science and Technology* **4** 027
- [43] Bennett A. 2012 Membrane technology: Developments in ultrafiltration technologies *Filtration and Separation* **49**(6) 28-33
- [44] Wenten IG. Instalasi unit ultrafiltrasi untuk penyediaan air minum di Desa Cisarua, Kabupaten Purwakarta, Jawa Barat. Report of community service activity 2016: LPPM - Institut Teknologi Bandung. 2016.
- [45] He Y 2009 Transportable membrane system produces drinking water. *Membrane Technology* **2009**(8) 8-9
- [46] Barbot E, Carretier E, Wyart Y, Marrot B, Moulin P. 2009 Transportable membrane process to produce drinking water *Desalination* **248**(1-3) 58-63
- [47] GDP Filter Indonesia 2017 IGW Emergency UF (Portable Hand Pump): G.D.P Filter Indonesia; [17th April]. Available from: <http://gdpfilter.co.id/>.
- [48] Li X, Rao Z, Yang Z, Guo X, Huang Y, Zhang J, et al. 2015 A Survey of 42 Semi-Volatile Organic Contaminants in Groundwater along the Grand Canal from Hangzhou to Beijing, East China *International journal of environmental research and public health* **12**(12) 16070- 81

- [49] Vandanjon L, Johannsson R, Derouiniot M, Bourseau P, Jaouen P. 2007 Concentration and purification of blue whiting peptide hydrolysates by membrane processes *Journal of Food Engineering* **83**(4) 581-9
- [50] Soffer Y, Aim RB, Adin A. 2005 Membrane fouling and selectivity mechanisms in effluent ultrafiltration coupled with flocculation *Water Science & Technology* **51**(6-7) 123-34
- [51] Ellouze F, Ben Amar N, Mokhtar MN, Zimmermann W, Deratani A. 2011 Fractionation of homologous CD6 to CD60 cyclodextrin mixture by ultrafiltration and nanofiltration *Journal of Membrane Science* **374**(1-2) 129-37
- [52] Pearce G 2007 Introduction to membranes: filtration for water and wastewater treatment *Filtration & separation* **44**(2) 24-7
- [53] Aryanti PTP, Subagio S, Ariono D, Wenten IG 2015 Fouling and rejection characteristic of humic substances in polysulfone ultrafiltration membrane *Journal of Membrane Science and Research* **1** 41-5
- [54] Lin J 2015 Membrane Technologies for Fractionation of Dye/Salt Mixture and Resource Reuse in Textile Industry (Leuven: Katholieke Universiteit Leuven)
- [55] Kramer FC, Shang R, Heijman SG, Scherrenberg SM, van Lier JB, Rietveld LC 2015 Direct water reclamation from sewage using ceramic tight ultra- and nanofiltration *Separation and Purification Technology* **147** 329-36
- [56] Lin J, Ye W, Baltaru M-C, Tang YP, Bernstein NJ, Gao P, et al 2016 Tight ultrafiltration membranes for enhanced separation of dyes and Na₂SO₄ during textile wastewater treatment *Journal of Membrane Science* **514** 217-28
- [57] Ma X, Chen P, Zhou M, Zhong Z, Zhang F, Xing W 2017 Tight ultrafiltration ceramic membrane for separation of dyes and mixed salts (both NaCl/Na₂SO₄) in textile wastewater treatment *Industrial & Engineering Chemistry Research* **56**(24) 7070-7079
- [58] Efligenir A, Déon S, Fievet P, Druart C, Morin-Crini N, Crini G 2014 Decontamination of polluted discharge waters from surface treatment industries by pressure-driven membranes: removal performances and environmental impact *Chemical Engineering Journal* **258** 309-19
- [59] Shang R, Verliefde AR, Hu J, Zeng Z, Lu J, Kemperman AJ, et al. 2014 Tight ceramic UF membrane as RO pre-treatment: The role of electrostatic interactions on phosphate rejection. *Water Research* **48** 498-507
- [60] Shang R, Verliefde AR, Hu J, Heijman SG, Rietveld LC 2014 The impact of EfOM, NOM and cations on phosphate rejection by tight ceramic ultrafiltration. *Separation and Purification Technology* **132** 289-94
- [61] Park N, Lee Y, Lee S, Cho J. 2007 Removal of taste and odor model compound (2, 4, 6-trichloroanisole) by tight ultrafiltration membranes *Desalination* **212**(1) 28-36
- [62] Lin Y, Cai Y, Qiu M, Drioli E, Fan Y 2015 Environment-benign preparation of Ag toughening TiO₂/Ti tight ultrafiltration membrane via aqueous sol-gel route. *Journal of Materials Science* **50**(15) 5307-17
- [63] Wang J, Lang W-Z, Xu H-P, Zhang X, Guo Y-J 2015 Improved poly(vinyl butyral) hollow fiber membranes by embedding multi-walled carbon nanotube for the ultrafiltrations of bovine serum albumin and humic acid *Chemical Engineering Journal* **260** 90-8
- [64] Vatanpour V, Madaeni SS, Khataee AR, Salehi E, Zinadini S, Monfared HA 2012 TiO₂ embedded mixed matrix PES nanocomposite membranes: influence of different sizes and types of nanoparticles on antifouling and performance *Desalination* **292** 19-29
- [65] Ariono D, Aryanti PTP, Subagio S, Wenten IG 2017 The effect of polymer concentration on flux stability of polysulfone membrane *AIP Conference Proceedings* **1788**(1) 030048
- [66] Setiawan L, Wang R, Li K, Fane AG 2011 Fabrication of novel poly (amide-imide) forward osmosis hollow fiber membranes with a positively charged nanofiltration-like selective layer *Journal of Membrane Science* **369**(1) 196-205
- [67] Himma NF, Wardani AK, Wenten IG 2016 Preparation of Superhydrophobic Polypropylene Membrane Using Dip-Coating Method: The Effects of Solution and Process Parameters *Polymer-Plastics Technology and Engineering* **56**(2) 184-194

- [68] Giménez-Pérez A, Bikkarolla SK, Benson J, Bengoa C, Stüber F, Fortuny A, et al. 2016 Synthesis of N-doped and non-doped partially oxidised graphene membranes supported over ceramic materials *Journal of Materials Science* **51**(18) 8346-60
- [69] Li J-F, Xu Z-L, Yang H, Yu L-Y, Liu M 2009 Effect of TiO₂ nanoparticles on the surface morphology and performance of microporous PES membrane *Applied Surface Science* **255**(9) 4725-32
- [70] Wang H, Zhao X, He C 2016 Enhanced antifouling performance of hybrid PVDF ultrafiltration membrane with the dual-mode SiO₂-g-PDMS nanoparticles *Separation and Purification Technology* **166** 1-8
- [71] Rajaeian B, Heitz A, Tade MO, Liu S 2015 Improved separation and antifouling performance of PVA thin film nanocomposite membranes incorporated with carboxylated TiO₂ nanoparticles *Journal of Membrane Science* **485** 48-59
- [72] Lan Q, Yan N, Wang Y 2017 Tight ultrafiltration membranes of mesoporous phenolic resin filled in macroporous substrates *Journal of Membrane Science* **533** 96-102
- [73] Kotte MR, Cho M, Diallo MS 2014 A facile route to the preparation of mixed matrix polyvinylidene fluoride membranes with in-situ generated polyethyleneimine particles. *Journal of Membrane Science* **450** 93-102
- [74] Karim Z, Claudpierre S, Grahn M, Oksman K, Mathew AP 2016 Nanocellulose based functional membranes for water cleaning: Tailoring of mechanical properties, porosity and metal ion capture *Journal of Membrane Science* **514** 418-28
- [75] Sadrzadeh M, Bhattacharjee S 2013 Rational design of phase inversion membranes by tailoring thermodynamics and kinetics of casting solution using polymer additives *Journal of Membrane Science* **441** 31-44
- [76] Aryanti PTP, Joscarita SR, Wardani AK, Subagio S, Ariono D, and Wenten IG 2016 The Influence of PEG400 and Acetone on Polysulfone Membrane Morphology and Fouling Behaviour *Journal of Engineering and Technological Sciences* **48**(2) 135-49
- [77] Barth C, Goncalves M, Pires A, Roeder J, Wolf B 2000 Asymmetric polysulfone and polyethersulfone membranes: effects of thermodynamic conditions during formation on their performance *Journal of Membrane Science* **169**(2) 287-99
- [78] Aryanti PTP, Khoiruddin, and Wenten IG 2013 Influence of additives on polysulfone-based ultrafiltration membrane performance during peat water filtration, *Journal of Water Sustainability* **3**(2) 85-96
- [79] Hamid N, Ismail AF, Matsuura T, Zularisam A, Lau WJ, Yuliwati E, et al. 2011 Morphological and separation performance study of polysulfone/titanium dioxide (PSF/TiO₂) ultrafiltration membranes for humic acid removal *Desalination* **273**(1) 85-92
- [80] Leo C, Kamil NA, Junaidi M, Kamal S, Ahmad A 2013 The potential of SAPO-44 zeolite filler in fouling mitigation of polysulfone ultrafiltration membrane *Separation and Purification Technology* **103** 84-91
- [81] Maximous N, Nakhla G, Wan W, Wong K. 2010 Performance of a novel ZrO₂/PES membrane for wastewater filtration *Journal of Membrane Science* **352**(1) 222-30
- [82] Shen J-n, Ruan H-m, Wu L-g, Gao C-j 2011 Preparation and characterization of PES-SiO₂ organic-inorganic composite ultrafiltration membrane for raw water pretreatment *Chemical Engineering Journal* **168**(3) 1272-8
- [83] Han R, Zhang S, Liu C, Wang Y, Jian X 2009 Effect of NaA zeolite particle addition on poly (phthalazinone ether sulfone ketone) composite ultrafiltration (UF) membrane performance *Journal of Membrane Science* **345**(1) 5-12
- [84] Leo C-P, Lee WC, Ahmad AL, Mohammad AW 2012 Polysulfone membranes blended with ZnO nanoparticles for reducing fouling by oleic acid *Separation and purification technology* **89** 51-6
- [85] Balta S, Sotto A, Luis P, Benea L, Van der Bruggen B, Kim J 2012 A new outlook on membrane enhancement with nanoparticles: the alternative of ZnO *Journal of membrane science* **389** 155-61

- [86] Taurozzi JS, Arul H, Bosak VZ, Burban AF, Voice TC, Bruening ML, et al. 2008 Effect of filler incorporation route on the properties of polysulfone–silver nanocomposite membranes of different porosities *Journal of Membrane Science* **325**(1) 58-68
- [87] Mollahosseini A, Rahimpour A, Jahamshahi M, Peyravi M, Khavarpour M 2012 The effect of silver nanoparticle size on performance and antibacteriability of polysulfone ultrafiltration membrane *Desalination* **306** 41-50
- [88] Kim YS, Yang SM 2002 Preparation of continuous mesoporous silica thin film on a porous tube *Advanced Materials* **14**(15) 1078-81
- [89] Jin Z, Yiqun F, Nanping X 2010 Preparation and characterization of alumina membranes on capillary supports: effect of film-coating on crack-free membrane preparation *Chinese Journal of Chemical Engineering* **18**(3) 377-83
- [90] Peeva PD, Palupi AE, Ulbricht M. 2011 Ultrafiltration of humic acid solutions through unmodified and surface functionalized low-fouling polyethersulfone membranes – Effects of feed properties, molecular weight cut-off and membrane chemistry on fouling behavior and cleanability *Separation and Purification Technology* **81**(2) 124-33
- [91] Chen X, Lin Y, Lu Y, Qiu M, Jing W, Fan Y 2015 A facile nanoparticle doping sol–gel method for the fabrication of defect-free nanoporous ceramic membranes *Colloids and Interface Science Communications* **5**(Supplement C) 12-5
- [92] Ariono D, Aryanti PTP, Hakim AN, Subagjo S, Wenten IG 2017 Determination of thermodynamic properties of polysulfone/PEG membrane solutions based on Flory-Huggins model *AIP Conference Proceedings* **1840** (1) 090008
- [93] Zhang R, Liu Y, He M, Su Y, Zhao X, Elimelech M, Jiang Z 2016 Antifouling membranes for sustainable water purification: strategies and mechanisms *Chemical Society Reviews* **45**(21) 5888-924
- [94] Aryanti PTP, Subagjo S, Ariono D, Wenten IG. 2015 Fouling and rejection characteristic of humic substances in polysulfone ultrafiltration membrane. *Journal of Membrane Science and Research* **1**(1) 41-45
- [95] Wenten IG, Aryanti PTP, Khoiruddin K, Hakim AN, Himma NF. 2016 Advances in Polysulfone-Based Membranes for Hemodialysis *Journal of Membrane Science and Research* **2**(2)78-89