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Ultrafiltration as a pretreatment for seawater desalination: A review

W.J. Lau [*1], P.S. Goh [1], A.F. Ismail [1] and S.O. Lai [2]

[1] *Advanced Membrane Technology Research Centre (AMTEC), Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor, Malaysia*
[2] *Chemical Engineering Department, Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Genting Kelang, 53300 Kuala Lumpur, Malaysia*

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Abstract. Reverse Osmosis (RO) desalination has gained wide and increasing acceptance around the world as a straightforward undertaking to alleviate the alarming water crisis. An enhanced monitoring of the quality of the water feeding in seawater RO (SWRO) plant through the application of an effective pretreatment option is one of the keys to the success of RO technology in desalination plants. Over the past 10 years, advances in ultrafiltration (UF) membrane technologies in application for water and wastewater treatment have prompted an impetus for using membrane pretreatment in seawater desalination plants. By integrating SWRO plant with UF pretreatment, the rate of membrane fouling can be significantly reduced and thus extend the life of RO membrane. With the growing importance and significant advances attained in UF pretreatment, this review presents an overview of UF pretreatment in SWRO plants. The advantages offered by UF as an alternative of pretreatment option are compared to the existing conventionally used technologies. The current progress made in the integration of SWRO with UF pretreatment is also highlighted. Finally, the recent advances pursued in UF technology is reviewed in order to provide an insight and hence path the way for the future development of this technology.

Keywords: reverse osmosis; desalination; pretreatment; ultrafiltration; integrated membrane system; fouling; seawater

1. Introduction

The origins of the desalination application using reverse osmosis (RO) membrane can be traced to the observation by Reid and Breton in the late of 1950s that dense polymeric films could be potentially used for desalting seawater for pure water production (Reid and Breton 1958). Shortly afterwards, Loeb and Sourirajan from University of California, Los Angeles (UCLA) developed the first synthetic asymmetric cellulose acetate membrane with an active skin layer thin enough to obtain high flux for industrial adoption (Loeb and Sourirajan 1962). Fast forward to the present day, the seawater desalination using RO technology has become an essential tool to enable effective management of water strategies in many countries such as Saudi Arabia, USA, UAE, China and Singapore.

*Corresponding author, Ph.D., E-mail: lwoeijye@utm.my, lau_woeijye@yahoo.com

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According to a market research report, the total sale of RO equipment is recorded at US$ 1.4 billion in 2010 and is expected to reach nearly US$ 3.2 billion in 2015 with a compound annual growth rate of 17.5% (Hanft 2010b). The continued growth of the market share indicates the confidence level of plant operators and/or consumers on the technology of the membrane-based desalination process. In general, seawater reverse osmosis (SWRO) desalination process offers many advantages over other desalination methods, e.g., multistage flash distillation, vapor compression, electrodialysis reversal and solar distillation. Nevertheless, many SWRO engineers and operators are facing ever increasing challenges with respect to RO membrane fouling which is resulted from formation of deposits on the membrane surface (Misdan *et al*. 2012). The main fouling mechanisms of RO membrane include colloidal fouling (particulate deposition), biofouling (microbial adhesion and growth), organic fouling (adsorption of organic compounds), and inorganic fouling (scaling) (Pontié *et al*. 2005). To tackle this problem, ultrafiltration (UF) membrane is employed prior to SWRO membrane and acts as pretreatment in reducing fouling, silt density index (SDI) and turbidity of water fed to the RO system. It must be pointed out that getting the pretreatment right is not only the key in ensuring the efficient operation of desalination plant but also offering a long term sustainable solution for RO investment and maintenance cost.

Many users were skeptical about role of UF as pretreatment compared to the conventional technologies at the early stage of UF implementation in desalination plant. But, the successful cases of using UF as a more effective pretreatment technology for SWRO desalination in the mid-2000s have led to many large-scale integrated UF-RO desalination plants built worldwide in the present days and many more such integrated membrane systems (IMSs) are currently under construction with completion due this year or next year.

Although a wide variety of research and general information on the use of UF as pretreatment prior to RO is available, the paper aims to provide updated information on the trend and progress of UF membrane technology in the integrated UF-RO membrane system for seawater desalination process. The content in this review is organized into four main subsections. Statistics showing the detailed information about primary UF manufacturers and UF suppliers particularly for SWRO pretreatment will be first provided followed by the comparison between conventional treatment technologies and UF membrane as option for SWRO pretreatment. A selection of new RO seawater desalination plants that has been benefited from UF membrane in recent years will also be provided to update the readers on the IMS for seawater desalination process. Attempts are also made to review the recent development of UF membrane technology in addressing its limitations being a pretreatment for SWRO.

2. Statistics on seawater desalination

Geological survey has found that 97% of the water on the Earth is located in the seas and oceans. Out of the 3% of fresh water resources, about 70% is in the form of ice and permanent snow cover in mountainous regions, the Antarctic and Arctic regions. Meanwhile, the remaining unfrozen freshwater is found mainly as groundwater, with only a small fraction present above ground or in the air. Water scarcity already affects almost every continent and more than 40% of the people on the planet. It is also predicted that by 2030, over one third of the world population, concentrated in developing countries, will be living in river basins that will have to cope with significant water stress (Goh *et al*. 2013). To worsen the situation, the clean water supplies have become more critical due to excessive use and increasing contamination of natural water sources.

As the demands of clean water continue to rise, improving the effectiveness and efficiency of water purification technology in a sustainable manner seems to be the most straightforward approach to avert the alarming water crisis.

One of the most pressing challenges is to recover clean drinking water from brackish or sea water which is the most abundant global water resource by far. In this context, desalination which is a technology that converts saline water into clean water, has offered one of the most important solutions to this problem (Lee *et al*. 2011)**.** The principle of desalination processes are generally classified into two major categories based on their separation mechanisms, i.e., thermal method and membrane method. In broad view, thermal distillation separates salt from water by evaporation and condensation, meanwhile membrane processes depend on the driving forces such as pressure across the semi-permeable membranes for the salt separation. Multistage flash evaporation, multi-effect distillation and vapor compression are the three well-established distillation methods that have been conventionally used to desalt seawater by boiling to produce water vapor that is then condensed into freshwater. On the other hand, RO is the most commonly used membrane process that provides a feasible solution to convert seawater into potable water in many regions. While thermal desalination has remained as the most widely applied desalination technology, particularly in the regions with abundant and low cost fossil fuel supply, desalination based on membrane technology has rapidly developed over the past 40 years (Macedonio *et al*. 2012). Due to the innovations and reliable future trends in the design and operation, RO technology has superseded the conventionally used thermal process in seawater desalination. It is anticipated that this technology will continue to possess the highest degree of current and future implementations.

Fig. 1 depicts the contribution of each desalination technique to 16,000 desalination plants worldwide (GWI (Global Water Intelligence) – IDA Desalination Yearbook 2011-2012). As published in the International Desalination Association (IDA)'s Desalination Yearbook 2011-2012, the estimated installed world capacity for desalination is 66.4 million m^3/day with RO plant accounting for 60% of the total. Compared to the data published in 1990 where RO plant contributed only 31% of the total capacity of 13.3 million m^3/day (Wangnick 1990), there is a tremendous increase of SWRO plants built worldwide for desalination process. Today, RO membranes are the leading technology with new desalination installation and they are applied to a variety of saltwater resources using tailored pretreatment and membrane system design (Greenlee *et al*. 2009). One of the major contribution to the high acceptance of SWRO is most probably the

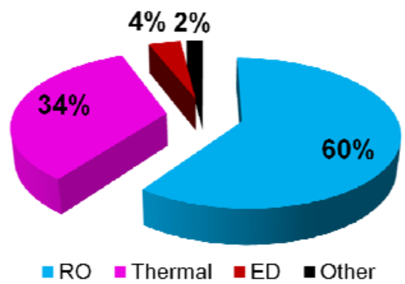

Fig. 1 The contribution of each desalination technique to 16,000 desalination plants worldwide with total capacity of 66.4 million m^3/day

drastically reduced energy consumption based on the development of more efficient membranes, the use of energy recovery devices, as well as the advances in producing new materials with less fraction and variable-frequency drive devices (Peñate and García-Rodríguez 2012). The improvement in desalination plants which entail significant decrease in energy consumption will undoubtedly be an advantage for obtaining the lowest water cost. Currently, the RO process energy consumption in medium-large capacity SWRO is approximately between 2.2 and 25 kWh/m^3 (Stover 2009). As a matter of fact, the statistics in Fig. 2 show that the thermal and membrane processes are almost equally sharing the global market in 2010 (Hanft 2010a). However, it is projected that membrane-based desalination processes will surpass and dominate the global market with about US$ 3.2 billion by 2015 (Hanft 2010b).

While RO membranes have been continuously improved over the years, this technology has had one major shortcoming, which is the susceptibility to fouling. The overall performance of RO desalination plants strongly depends on high quality feed water to ensure reliable and stable operation of the RO system. Indeed, the contemporary findings showed that RO technology is limited in hydraulic performance by the raw water quality. This phenomenon is particularly true when direct seawater intake is considered, in which extensive treatment is required at the upstream of the RO process. Thus, an IMS is highly desired to treat the surface seawater or brackish water. In this context, pretreatment with UF membranes has been given strong consideration. UF membranes that have been proven their separation capability in a wide range of much more difficult liquid environments such as municipal and industrial wastewaters, have now been identified as an option for pretreatment solution. Fig. 3 shows the major manufacturers of UF membranes for all applications along with their apparent market share (Hanft 2010a). These membranes have been successfully employed in a wide range of industries which include food and beverage industry, hemodialysis, potable water treatment, wastewater treatment and biopharmaceutical industry. Nevertheless, it must be pointed out that the figures shown might not completely describe the actual market share of each manufacturer. It is mainly because the field is highly competitive and many are reluctant to offer opinions, making it difficult to establish market share for UF membrane and its applications.

Over the last decade, UF membrane has been promisingly applied in RO treatment plant as the

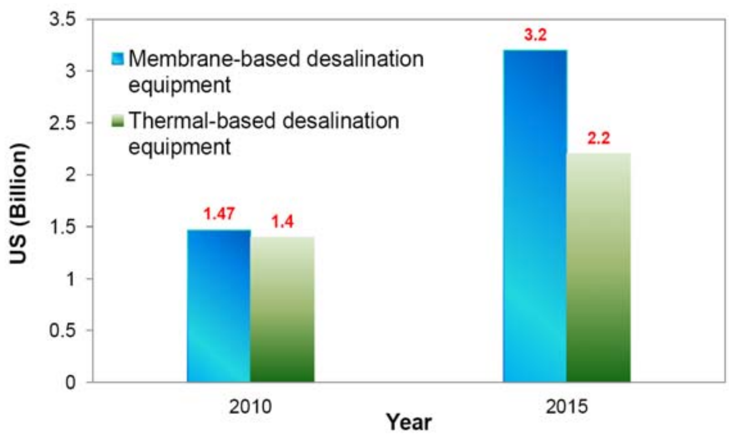

Fig. 2 Global market for membrane-based and thermal-based desalination equipment

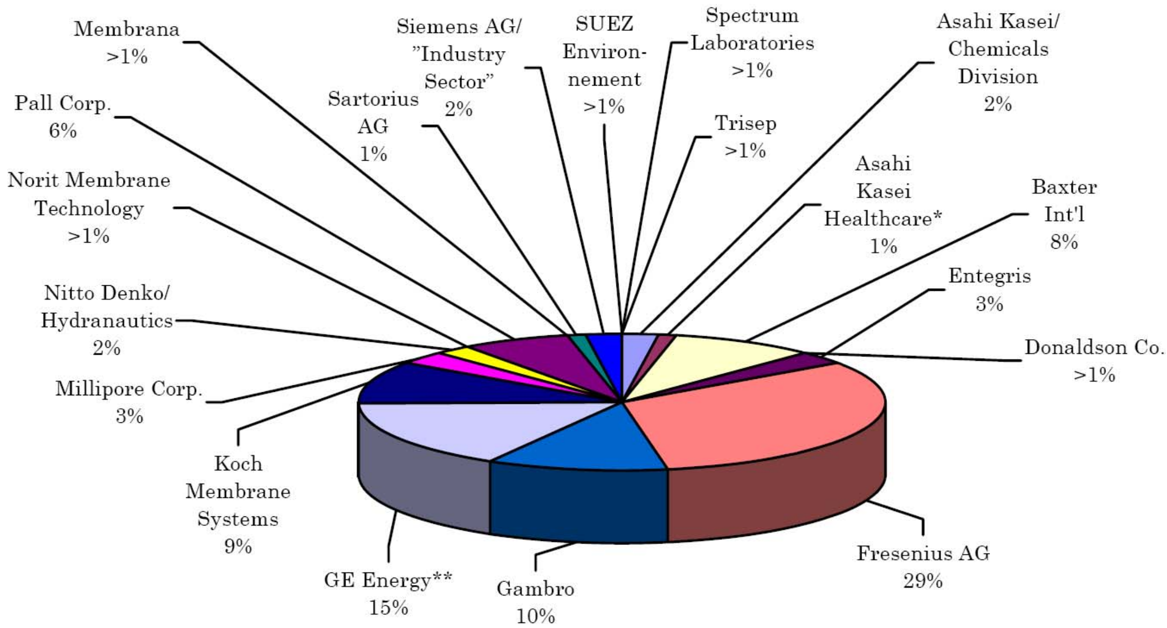

Fig. 3 Primary players and share (%) of the UF market in 2 (Remarks: *includes joint venture Asahi Kuraray Medical, **includes GE Water/GE Healthcare)

pretreatment filter. The combination of UF with RO system helps in controlling the RO membrane fouling and providing filtered water in steady state conditions. The UF pretreatment also provides filtered water with high and constant quality that enhances the reliability of the RO desalination plant. Fig. 4 shows the main MF/UF membrane suppliers for SWRO pretreatment (GWI 2011). The contribution (in %) of membrane suppliers towards SWRO pretreatment was determined based on the installed UF pretreatment capacity. As can be seen, Hyflux was the major contributor followed by Norit and their total installed capacities of UF were close to two-thirds of the worldwide installed capacities. It has been reported that the installed UF pretreatment capacity was less than 200,000 m^3/day in its earlier application for SWRO treatment plants. However, it began to increase rapidly from 2005 and exceeded 1 million m^3/day by 2008 (GWI 2011).

3. Pretreatment options: Membrane vs conventional technologies

Pretreatment is an essential step to reduce various forms of fouling and scaling rates, hence to preserve performance and life span of membranes. RO desalination plants that equipped with inadequate or less effective pretreatment measures may suffer from undesired low system performance. As a result, RO system can experience high rate of membrane fouling, high frequency of membrane cleaning, lower recovery rate, high operating pressure and reduced membrane life span. Consequently, the operating costs are significantly increased. In general, pretreatment operations can be performed through physical and chemical means. The former pretreatment applies mechanical filtration through screening, sedimentation, cartridge filters, sand

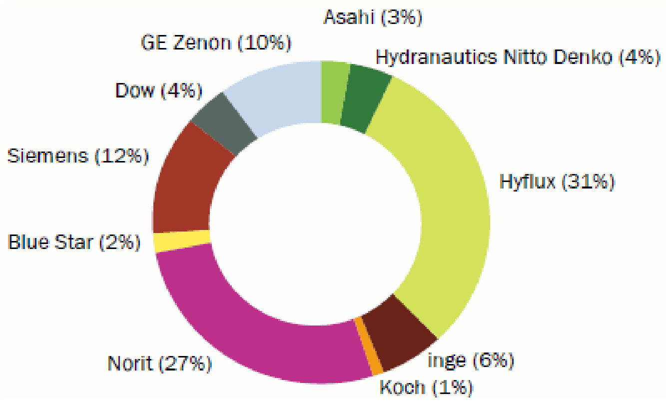

Fig. 4 MF/UF membrane suppliers for SWRO pretreatment (by % of installed capacity)

filters and membrane filtration whereas the latter involves the addition of scale inhibitors, coagulants and disinfectants that normally responsible for pH adjustment, increasing the solubility of salts and disinfection (Macedonio *et al*. 2012).

In a RO desalination plant, the clarification of seawater upstream RO is typically carried out using conventional or membrane pretreatment methods. Since the content and nature of foulants presents in the source seawater depend on the type and location of the desalination plant intake, both conventional and membrane-based pretreatment technologies may offer solutions or face the bottlenecks depending on the source seawater quality and origin. The effectiveness of alternative UF systems compared to conventional systems can be generally evaluated in terms of (i) the quality and variability of the feed water; (ii) the capacity of the RO system and the space available; (iii) the amount of cleaning or maintenance required for the pretreatment system and last but not the least (iv) the reliability, capital and operating cost of the membrane and conventional system (Durham *et al*. 2001).

Despite the fact that in the past the conventional RO physical and chemical pretreatment has dominated over that of applying membrane technology, the performance of these conventional approaches is very susceptible to inconsistent filtrate water quality and the proper dose of chemical usage is difficult to meet if feedwater quality varies rapidly. In addition, the conventional pretreatment often do not represent a positive barrier to suspended solid and the presence of coagulant residuals can negatively affect RO membrane performance when either Al/Fe salts or chloramines are used. As a result, design permeate flux rate and recovery of the seawater RO plants are lowered in order to ensure stable long-term performance. Although some research works have indicated that the conventional methods such as coagulation could remove most of the foulants and decrease the resistance of membrane filtration, unfortunately the rate and extent of fouling could not be mitigated by conventional pretreatment (Chen *et al*. 2007). With respect to the shortages of conventional pretreatment for the continually deteriorating feedwater quality, an increasing number of plant operators have started to place their attentions towards the use of membrane technology to replace the less efficient conventional pretreatment systems. The switching is further prompted by the declining membrane cost and enhanced membrane performance with the constantly improved membrane science and technology.

Membrane pretreatment has been identified as a very promising and advantageous to RO system that treats both seawater open intakes and brackish surface water (Bonnélye *et al*. 2008). Due to the effectiveness in removing organic and particulate matter in feed surface water that commonly suffers from high colloidal and suspended solids as well as severe variability and sporadic issues, the implementation of membrane pretreatment has guaranteed a better performance of RO system in aspect of higher permeate flux and reduced fouling and destruction of RO membranes.

Membranes with larger pore size such as microfiltration (MF), UF and nanofiltration (NF) have been ever reported in literature to pretreat RO feed water. Nevertheless, UF membrane that has smaller pore sizes than MF but larger than that of NF seems to represent the best balance between contaminant removal and permeate products among these membrane types. UF membrane has been shown to be very efficient in removing turbidity and non-soluble and colloidal organics contained in the source seawater. In contrast to MF membrane, UF membrane can also effectively remove viruses and prevent biofouling on SWRO. When compared to NF membranes, UF membranes could promote higher flux so that it is more economically viable. Although UF membrane in general has pore size in the range of 0.01–0.1 μm, the pore size of between 0.01 and 0.02 μm is found the most suitable to be employed as pretreatment for SWRO desalination process. Table 1 lists some of the commercial UF hollow fiber products with that particular range of pore size that are widely used as pretreatment for SWRO desalination process (Hanft 2010a, Hyflux Ltd. 2013, Li *et al*. 2012).

Pretreatment based on UF is attractive yet like other conventional methods, it is also not free from some serious concerns. One of the great obstacles that hinders the wide application of the membrane pretreatment technology is the general negative perception towards UF as a pretreatment option that is technically feasible but economically unviable based on the higher operating cost of UF when being compared with conventional pretreatment. In fact, economic evaluation of different SWRO desalination plants with conventional pretreatment or with UF

Table 1 Some commercial UF membranes with pore size between 0.01 and 0.02 μm

Manufacturer	Product (polymer[a])	Filtration mode	Pore size (μm)	Reference
Norit	XIGA (PES)	Pressure-driven, inside-out	0.02	Hanft (2010a)
	Seaguard (PES)	Pressure-driven, inside-out	0.02	
GE Water	ZeeWeed® 1500 (PVDF)	Pressure-driven, outside-in	0.02	
Hydranautics	HYDRAcap (PES)	Pressure-driven, inside-out	0.02	
Aquasource	Aquasource (CA)	Pressure-driven, inside-out	0.01	
	Alteon (CA)	Pressure-driven, inside-out	0.01	
Koch	Romicon PMPW (PS)	Pressure-driven, inside-out	0.01	
Hyflux	Kristal® 600 Series (modified PES)	Pressure-driven, outside-in	~0.01[b]	Hyflux Ltd. (2013)
X-Flow	PES/PVP	Pressure-driven, inside-out	~0.01[c]	Li *et al.* (2012)

[a] PES: Polyethersulfone; PVDF: Polyvinylidene difluoride; CA: Cellulose acetate; and PS: Polysulfone; PVP: Polyvinylpyrrolidone
[b] The pore size is corresponded to 120 kDa as reported by manufacturer
[c] The pore size is corresponded to 100 kDa as reported by manufacturer

pretreatment has indicated that using UF membrane as pretreatment to SWRO desalination plants does not apparently increase the cost associated with the pretreatment (Knops *et al*. 2007). Even when the additional cost of replacing the UF membranes at the end of their useful life time is considered, it is believed that this cost can be offset by the cost reduction in use of chemicals.

4. Integrated Membrane System (IMS) for seawater desalination

4.1 Principle of UF-RO IMS

The key to the successful operation of SWRO plant is dependent on feed pretreatment process. Of the wide pore size range of UF membranes available in the current market, UF with a nominal pore size of around 0.02 μm is known to be the most effective in removing potential elements such as silt, algae, bacteria, and large molecular weight of organic matters responsible for RO fouling and consistently producing permeate with turbidity below 0.1 NTU and 15-min Silt Density Index (SDI_{15}) less than 2.5, provided the specified feed parameters are not exceeded. Turbidity is a measure of water clarity on how much the suspended materials in water decrease the passage of light through the water while SDI_{15} is a measure of the amount of sub-micron particulates present in water and is determined by monitoring the flux decline over 15 min period when the feed water is filtered continuously through a 0.45 μm membrane at transmembrane pressure of 30 psi. Since the separation mechanism of UF is governed by sieving effect, filtrate produced is generally very consistent in terms of quality and not very much dependent on feed water characteristics.

Fig. 5 illustrates a typical IMS consisting of UF and RO membranes for SWRO process. With the employment of two different membrane processes in the IMS, multiple treatment objectives can be achieved. It must be noted that the presence of sharp objects such as broken shells and broken glasses in the source water could potentially scratch the surface of UF, causing the irreversible loss of membrane integrity. Previous data obtained from the Carlsbad seawater desalination demonstration plant and West Basin seawater pilot plant in California, USA revealed that screen size > 120 μm does not provide sufficient protection for UF against sharp objects in seawater (Li *et al*. 2008, Voutchkov 2010). Therefore, fine microscreen of 120 mm or smaller is

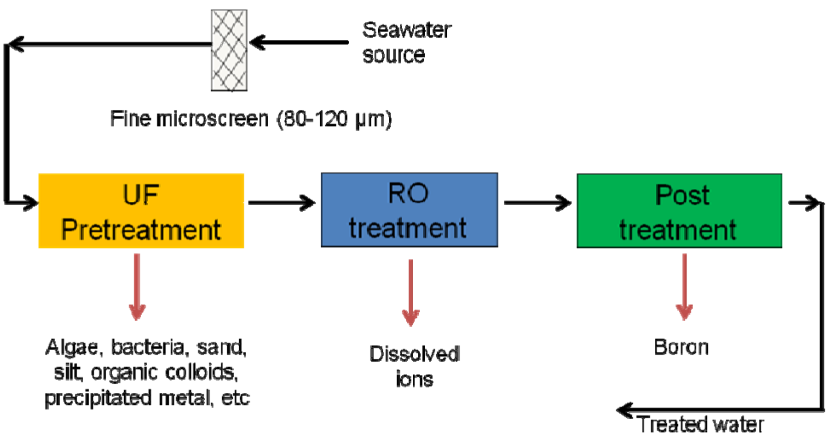

Fig. 5 Typical integrated membrane system for seawater desalination process

highly recommended to install ahead of the UF to protect the membrane elements from damage. Besides retaining sharp objects from permeating through membrane elements, fine microscreen could also retain barnacles which in their embryonic phase of development are 130-150 μm in size. It must be pointed out that the inefficiency of microscreen in eliminating barnacle plankton could result in the growth of colonies which might attach to the walls of downstream pretreatment facilities, interfering the operation of pretreatment process.

4.2 Unique advantages of using UF in IMS

In addition to the higher quality of the feed stream entering RO system, other significant advantages of using UF pretreatment in SWRO desalination plant include:

(1) reliable separation performance – even in the challenging feed water conditions (with very high turbidity), UF membrane is still able to produce a very consistent permeate quality for RO system. A pilot test conducted at Tianjin Gagang desalination plant in China revealed that there were no operational issues for UF to consistently produce permeate with turbidity of 0.1 NTU over a six-month testing period, even the feed turbidity could spike up to between 60 and 80 NTU (around 15% of the operation time) during the trial (Hyflux Ltd. 2013). Other relevant articles reporting the effectiveness of UF membrane in handling high turbidity seawater could also be found in (Kim *et al*. 2013, Zhang *et al*. 2006).

(2) small footprint – membrane pretreatment technology is very space efficient than conventional system, taking up less than 50% of the area of a conventional pretreatment system (Galloway and Mahoney 2004). As reported by Kennedy/Jenks Consultants, for a SWRO desalination plant of 10 MGD capacity, membrane pretreatment occupies only around 14,000 square foot (sq. ft.) in comparison to around 31,000 sq. ft. required by conventional pretreatment process (Frenkel and Lozier 2009). The small footprint of UF pretreatment is of great importance when the site area is limited and/or land cost is the main concern.

(3) reduction in chemical use and chemical waste disposal – the elimination of coagulant agent used (e.g., ferric chloride) in UF pretreatment coupled with reduced frequency of RO membrane cleaning result in significant reduction in chemical consumption and waste sludge generation (containing high concentration of metal) in desalination plant, making UF pretreatment more environmentally friendly (Li *et al*. 2008). Nevertheless, under certain circumstances (e.g., extremely high turbidity and high organic content), low amount of coagulant might be used in an effort to maintain the good performance of UF.

(4) low energy consumption – UF system is found to use significantly less energy in the overall pretreatment process compared to the sedimentation-based pretreatment (0.07 versus 0.22 kWh/m^3) after taking into the consideration the energy required by feed pump, backwash pump and air scouring/blower (Al-Sarkal and Arafat 2013). The high energy consumed by conventional pretreatment is mainly caused by the additional pumping energy required for the final cartridge filter which accounts for about 30% of the total energy in that system.

(5) reduced environmental impact – compared to conventional pretreatment, UF pre-treatment is reported to be able to reduce more than 30% environmental impact which is determined based on Environmental Score Index. The important factors that weigh against conventional pretreatment are its extensive use of concrete, large footprint, high energy

Table 2 Latest on UF-RO IMS for desalination process

Location	Capacity (m^3 desalinated water/day)	Year	Reference
Teshi, Ghana	60,000	2014	D&WR (2013)
Accra, Ghana	60,000	2014	Filtration + Separation (2013)
Al Jubail, Saudi Arabia	58,500	2013	Stedman (2013)
Tuas, Singapore	318,500	2013	Membrane Technology (2011)
Ashdod, Israel	~ 274,00	2013	Membrane Technology (2012b)
Ghallilah, United Arab Emirates	68,000	2013	Membrane Technology (2012a)
Ajman, United Arab Emirates	115,000	2012	D&WR (2012)
Hebei, China	50,000	2012	WDS (2012)
Tangshan, China	110,000	2012	Bennett (2012a)

consumption and high chemical usage. However, owing to the subjective nature of some of the inputs, the sustainability assessment might lead to different results for other cases (Pearce 2010).

4.3 Challenges of UF petreatment

Table 2 presents a selection of new RO seawater desalination plants that have been benefited from UF membrane in recent years with some of them are still under construction and will only come on line next year. Although UF has been successfully employed in many large-scale seawater desalination plants at the present day, many users were in fact sceptical on the effectiveness of UF as pretreatment option for RO desalination at the early stage of its implementation. But, thanks to the continuous incremental improvements in UF technology in terms of material and module design over the years, UF technology has emerged as well acceptable pretreatment in desalination applications and a further increase in the membrane pretreatment applications for desalination can be anticipated in the near future.

Similar to RO, one of the biggest issues remaining in UF pretreatment process is the fouling problem. Compared to other types of fouling, biofouling is perhaps the most obvious fouling threat encountered by UF pretreatment. Thus, no plant operator can afford to ignore the potential of biofouling. Biofouling of UF membrane is mainly caused by organic materials, which are amplified during algae bloom periods (also referred to as Red Tides or Harmful Algae Blooms) (Bennett 2012b). Algae could constantly secrete extracellular polymer substances (EPS) (composed mainly of polysaccharides and proteins), to form a viscous, slimy and hydrated gel on membrane surface for bacteria to attach and proliferate. This as a result contributes significantly towards membrane biofouling. In addition to the detrimental effects of increased transmembrane pressure and decreased permeate flux, biofouling may cause chemical degradation of the membrane material, reducing membrane lifetime. Among the techniques available to overcome this membrane limitation, development of a less-fouling-sensitive UF membrane is the most sustainable solution to counter or minimize biofouling potential. In the following section, a brief review on the latest development on membrane material to address this issue will be provided together with the other advancements in developing high flux membrane with no compromise in separation efficiency.

5. UF technology

5.1 Continuous improvement in UF echnology

Although the market is now settled with well-established UF products, there are still significant improvements in membrane performance being introduced by the market leaders every year. This section does not intend to provide an exhaustive review of all the UF membranes developed to date; it will instead focus on the recent research activities on the improvements of UF membrane properties in particular fouling resistance and water permeability.

As mentioned in the earlier section, the accumulation of algal cells and EPS on the membrane surface can cause a serious membrane fouling due to bacteria growth, although UF faces no problem in removing completely the microorganism by size exclusion. Modifying the original membrane properties therefore is very important to overcome the fouling problem in membrane. Nowadays, researchers are actively engaged in developing inexpensive fouling-resistant membrane by using techniques, including blending with hydrophilic species or inorganic nanoparticles, grafting hydrophilic species onto membrane surface, and introducing metal ion into membrane matrix.

5.2 Advanced materials in UF membrane development

To effectively promote antibacterial effect on polymeric membrane, silver (Ag) is embedded into membrane matrix as an innovative potential solution to mitigate biofouling. Ismail and his research team have found that polyethersulfone (PES)-Ag membrane could be potentially used in improving membrane performance with respect to the antibacterial activity by adding polyvinylpyrrolidone (PVP) as dispersant and 2,4,6-triaminopyrimidine (TAP) as compatibilizer into polymeric dope solution containing PES and silver nitrate ($AgNO_3$) (Basri *et al*. 2012, 2011). Other than $AgNO_3$, the addition of sodium zirconium phosphate nanoparticles ($Ag_{0.16}Na_{0.84}Zr_2(PO_4)_3$) into PES dope solution was also reported by Huang *et al*. (2012) in recent year and the results showed that the incorporation of small quantity of nanoAgZ particles could improve not only the hydrophilicity and water flux of membrane but also its antibacterial performance. The results obtained from the disk diffusion method revealed that PES-nanoAgZ membranes were less susceptible to the bio-films caused by the growth of both *E. coli* and *Pseudomonas sp*.

The presence of natural organic matters (NOM) such as humic acid (HA) and fulvic acid (FA) in the seawater source can also have a detrimental effect on membrane performance as it can result in irreversible fouling during water filtration. The concentration of NOM in the seawater however varies with the water source location and depends on weather in which heavy rainfall may cause its concentration to increase. A research work conducted by Schäfer *et al*. (2000) showed that HA caused a 78% decline in membrane flux compared to 15% in FA. This scenario might be due to its high aromaticity properties, adsorptive behaviour, hydrophobicity and greater molecular weight that led to the tendency to foul. A review paper written by Zularisam *et al*. (2006) has summarized that hydrophobic membrane tends to foul more than a hydrophilic membrane while the membrane surface with a positive charge tends to adsorb negatively functional groups of NOM, thus increasing the potential of fouling. NOM adsorption is greater for hydrophobic membranes such as PES and polysulfone (PSf) than for hydrophilic membranes made of cellulose acetate (CA). In order to tackle fouling problem due to NOM adsorption, the use of membranes with high degree of hydrophilicity and negatively charged is a better option.

In recent years, incorporating inorganic fillers into membrane matrix to prepare composite membrane for enhancing membrane performance has attracted a lot of attention owing to their small particle sizes, high surface area and hydrophilic nature (Arthanareeswaran and Thanikaivelan 2010, Jamshidi Gohari *et al*. 2013, Emadzadeh *et al*. 2014). Of the nano-materials ever studied (e.g., titanium dioxide (TiO_2), zirconium oxide (ZrO_2), silica (SiO_2), alumina (Al_2O_3), carbon nanotube (CNT), clay, etc.), TiO_2 nanoparticle is the main research focus of membrane scientists in preparing UF composite membranes. It is generally agreed that the addition of TiO_2 into membrane matrix could play a key role in promoting membrane water permeation rate and/or its antibacterial properties when membrane process is integrated with UV/visible light. Studies have attributed the increase in water permeability upon TiO_2 addition to enhanced membrane hydrophilicity and/or increase in membrane pore size/porosity (Hamid *et al*. 2011, Zhao *et al*. 2012). However, excessive addition of TiO_2 could result in poor membrane performances in which both water flux and solute rejection tend to decrease, most likely due to the agglomeration of TiO_2 nanoparticles, which reduces the contact area of hydroxyl groups carried by TiO_2 nanoparticles. Instead of utilizing TiO_2 directly, recent research works have focused on the modification of TiO_2 properties using silane coupling agent–3-aminopropyltriethoxysilane (APTES) (Razmjou *et al*. 2012) or coating multiwalled carbon nanotube (MWCNT) with TiO_2 (Vatanpour *et al*. 2012) to minimize the possible defects caused by unmodified TiO_2 on membrane surface.

On the other hand, the use of amphiphilic copolymer whether as an additive or main membrane forming material in UF membrane fabrication has also become the research focus of many researchers in recent years in an effort to modify membrane surface and internal pore properties, in particular degree of hydrophilicity and fouling resistance. Through polymerization of one or more monomers, amphiphilic copolymers of different characteristics can be synthesized. The copolymer polymerization would introduce specific properties to a material while maintaining unique characteristics of parent polymer. Some of the outstanding characteristics of copolymer that have been reported for membrane preparation are poly(N,N-dimethylamino-2-ethylmethacrylate)-*block*-polysulfone-*block*-poly(N,N dimethylamino-2-ethylmethacrylate) (PDMAEMA-*b*-PSF-*b*-PDMAEMA) (Zhao *et al*. 2013), poylsulfone-*random*-poly(ethylene oxide) (PSf-*r*-PEO) (Cho *et al*. 2011), polyethylene glycol-*graft*-polyacrylonitrile (PEG-*g*-PAN) (Su *et al*. 2009), polyacrylonitrile-*block*-polyethylene glycol (PAN-*b*-PEG) (Chen *et al*. 2011), polyacrylonitrile-*graft*-poly(ethylene oxide) (PAN-*g*-PEO) (Asatekin *et al*. 2007) and poylsulfone-*block*-polyethylene glycol (PSf-*b*-PEG) (Ma *et al*. 2007). Although membranes made of copolymer are always reported to perform better during filtration process compared to common polymeric materials, variables such as chain length of hydrophilic segments, mass fraction of hydrophilic segments in copolymer and composition of copolymer additive in dope solution need to be carefully studied during membrane preparation in order to produce high quality of membrane (antifouling properties) with no compromise in selectivity.

6. Conclusions

Desalination has become an essential tool to enable effective management of water strategies in the 21st century. RO membrane plays a large and important role in the municipal desalination market due to the reliability and viability of this desalination technology. The application of RO for desalination has increased rapidly with the construction of large RO plants worldwide. The continued growth of the market share indicates the confidence level of plant operators and/or consumers on the technology of the membrane-based desalination process. In general, SWRO membrane process offers many advantages over other desalination methods. Nevertheless, the most significant operation and maintenance problem encountered in RO process is membrane fouling, which has unfavorably deteriorate the performance of the RO system. To address this problem, UF membrane is combined with RO membrane to form an integrated membrane system to reduce and control membrane fouling. Despite the relatively new of UF technology for seawater pretreatment, over the past decade, more than two dozen of large full-scale SWRO membrane plants with membrane pretreatment have been constructed worldwide. It is anticipated that the technological advancements will result in an exponential growth of membrane pretreatment applications for seawater desalination. After all, underlying the development of a well accepted UF pretreatment for SWRO is the economic value of the desalinated water as well as the quality of the product water which is driven by regulations and technology. Innovative membrane has been designed and developed with the aim of tailoring it towards the practical applications as SWRO pretreatment option with lower total cost of ownership. An enhanced monitoring of the quality of the water feeding SWRO plant through the application of an effective pretreatment option deemed to be one of the keys to the success of this technology. With the accelerated advancement of membrane technology and continuing decreased membrane-manufacturing costs through technological innovation, an increase in the number of membrane pretreatment applications for desalination can be anticipated in the near future. Nevertheless, a number of technical challenges encountered in the existing UF systems for desalination process should be addressed in order to create a competitive advantage of UF systems over conventional technologies in desalination industry

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