Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2015.1054891

57 (2016) 7711–7720
April

Taylor & Francis
Taylor & Francis Group

Characterization of hydrophilic nanofiltration and ultrafiltration membranes for groundwater treatment as potable water resources

Norherdawati Kasim[a,c], Abdul Wahab Mohammad[b,*], Siti Rozaimah Sheikh Abdullah[a]

[a]*Faculty of Engineering and Built Environment, Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia, emails: herdawati@upnm.edu.my (N. Kasim), rozaimah@eng.ukm.my (S.R.S. Abdullah)*
[b]*Faculty of Engineering and Built Environment, Research Centre for Sustainable Process Technology (CESPRO), Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia, Tel. +60 3 89216410; Fax: +60 3 89216148; email: wahabm@eng.ukm.my*
[c]*Department of Chemistry, Centre for Defence Foundation Studies, National Defence University of Malaysia, Kem Sg. Besi, 57000 Kuala Lumpur, Malaysia*

Received 31 January 2015; Accepted 30 April 2015

ABSTRACT

In this work, two hydrophilic nanofiltration (NF) membranes and a tight ultrafiltration (UF) membrane were studied for drinking water production from groundwater resources. Commercial membranes denoted as TS40, TFC-SR3, and GHSP were selected to investigate their performances. It was found that both NF membranes were hydrophilic with contact angle at 28˚and 46˚, respectively. The tight UF membrane was hydrophobic at contact angle of 68˚. In the permeation test, both NF membranes exhibited higher permeability in pure water (4.68 and 3.99 $L\,m^{-2}\,h^{-1}\,bar^{-1}$) than UF membrane (3.15 $L\,m^{-2}\,h^{-1}\,bar^{-1}$). The order of single salt rejection by NF membranes were identified as R (Na_2SO_4) > R ($MgCl_2$) > R (NaCl), whereas for UF membrane was R (Na_2SO_4) > R (NaCl) > R ($MgCl_2$). A primary assessment of groundwater treatment for potable water showed that the highlighted components were characterized mainly by color, turbidity, and total dissolved solid (TDS) at 49 PtCo, 14 NTU, and 25 mg/L, respectively. The NF membrane, especially the TFC-SR3, was more efficient at rejecting these components, in quantities of 3 PtCo of color, 0.2 NTU of turbidity, and 10.5 mg/L of TDS, whereas the UF membrane attained 23 PtCo of color, 1.7 NTU of turbidity, and 17.6 mg/L of TDS. In conclusion, the findings on the quality of treated water verified that hydrophilic NF membrane performed well as a promising new technology for groundwater treatment in Malaysia.

Keywords: Groundwater; Membrane characterization; Hydrophilic and nanofiltration membrane

*Corresponding author.

Presented at the 7th International Conference on Challenges in Environmental Science and Engineering (CESE 2014) 12–16 October 2014, Johor Bahru, Malaysia

1. Introduction

In Malaysia, most of the water resources supplied for domestic usage was treated from surface water resources. However, recently, the increasing demand for sustainable development of water resources has resulted in the need for more systematic exploration and management of groundwater resources. Groundwater in Malaysia accounts more than 90% of the freshwater resources and the volume of groundwater recharge amounting to approximately 120 billion m^3 [1]. Nowadays, exploitation of groundwater in Malaysia has been increasing due to factors such as surface water depletion during dry seasons together with increased of water demand due to rapid population growth, agricultural, and industrial expansion. In addition, the utilization of groundwater can help to solve the water shortage in areas where surface water source sites are limited [2]. For these reasons, groundwater treatment for potable water resources in this country has high potential to be explored and commercialized for future benefits.

Potable water quality is very important for human health and therefore, any small amounts of hazardous contaminant are strictly forbidden [3]. All produced potable water should be thoroughly inspected to achieve drinking water standard that is set by the World Health Organization (WHO). As reported by the Department of Geoscience and Minerals Malaysia, unsuitability of groundwater for drinking was due to its high level of iron (Fe) and manganese (Mn) that resulted in metallic taste for consumption and rusty brown in color. Therefore, WHO recommends that Fe and Mn concentration in potable water should be less than 0.3 and 0.1 mg L^{-1}, respectively [4].

There were many methods that have been implemented for potable water production and membrane technology was among the top to be discussed for better improvement in the next decade [5–7]. Membrane filtration processes involving microfiltration (MF), ultrafiltration (UF), and nanofiltration (NF) in potable water production have increased rapidly over the past decade [8,9]. MF and UF are employed to remove microparticles and macromolecules, which generally include inorganic particles, organic colloids such as microorganisms, and dissolves organic matter [10]. NF membranes have the potential to remove turbidity, microorganisms and hardness, as well as a fraction of the dissolved salts. NF can either be used to treat all kinds of water including ground, surface, and wastewater or also used as a pretreatment for desalination [11].

In water treatment process, higher flux and lower operating pressure of nanofiltration makes the membrane feasible to be applied [12]. Therefore, hydrophilic membranes with high water permeation flux will normally be selected to maximize the production and minimizing its operation and maintenance costs. However, membranes with good selectivity and high removal of contaminants or pollutants should also be considered for water treatment purposes. Thus, tight UF membrane was also characterized and tested in this work to measure its ability for potable water production using groundwater resources.

The major objective of this work was to characterize and evaluate commercially available hydrophilic NF and tight UF membranes for groundwater treatment. Further investigations were conducted based on their removal performances and potential for potable water production. Therefore, membranes denoted as TFC-SR3, TS40, and GHSP were selected and tested to explore their characteristics and suitability for achieving the aims of this work.

2. Materials and methods

2.1. Feedwater and sampling point

Natural groundwater was used throughout the filtration experiments. Groundwater samples were collected from a deep tube well which is located at Natural Hydraulic Research Institute of Malaysia in Serdang, Selangor. The total depth of well is 100 m with 150 mm diameter of the tube. This sampling location was selected because of the water quality is almost similar to groundwater in North Kelantan as presented in Table 1. A volume of 20 L groundwater sample was collected for experimental use and was abstracted using a stand in hydrocontrol pump connected to the well. The groundwater samples were kept in a cold room right after sampling. The characteristics of groundwater samples were analyzed by ALS Technichem Laboratory, Malaysia.

2.2. Membrane characterization

Three commercially available flat sheet NF and UF membranes were employed in this study. All NF (TFC-SR3 and TS40) and UF (GHSP) membranes were supplied by Sterlitech Corp., USA. The membranes' characteristics are summarized in Table 2. The hydrophobicity of membrane surface was analyzed by contact angle measurements using a static sessile drop method by Goniometer contact angle (Ramé-Hart, Model 290, Netcong, USA) with three series of measurement at three different spots. Images of the top surface and cross-sectional morphologies of membranes were provided by Zeiss SUPRA 55VP FESEM

Table 1
Physical and chemical characteristics of groundwater samples and treated water

Sample	KB 12[a]	KB 31[b]	KB 36[c]	NAHRIM[d]	Benchmark[e]
pH	7.2	4.2	6.9	5.5	6.5–9.0
Conductivity (μS/cm)	1,166	575	145	65	250
Color (PtCo)	5	5	5	NR	15
Turbidity (NTU)	13	12	44	14	5
TDS ($mg L^{-1}$)	480	784	68	25	1,000
Cation ($mg L^{-1}$)					
Ca	12	35	2.9	3.21	500
Mg	14	35	2.0	1.18	150
Na	94	100	2.9	7.02	200
K	11	34	5.8	1.26	NR
Fe	10	90	8.1	7.01	0.3
Mn	0.2	0.8	0.3	0.83	0.1
Zn	<0.1	<0.1	<0.1	0.1	3.0
Pb	<0.01	<0.01	<0.01	<0.01	0.01
Cu	<0.1	<0.1	<0.1	<0.1	1.0
As	<0.01	<0.01	<0.01	<0.01	0.01
Al	<0.1	<0.1	<0.1	0.15	0.2
Anion ($mg L^{-1}$)					
F	<0.5	<0.5	<0.5	<0.1	0.4–0.6
Cl	235	436	3.0	6.6	250
SO_4	<5	<5	<5	3.5	250
HCO_3	114	<1	27	13	NR
CO_3	<1	<1	<1	<0.5	NR
NO_3	2.5	<0.5	3.9	0.1	10

Note: NR—Not reported.
[a,b,c]Minerals and Geoscience Department of Kelantan, Malaysia.
[d]Hydrogeology Research Centre, National Hydraulic Research Institute of Malaysia.
[e]Drinking Water Quality Standard, Ministry of Health Malaysia.

Table 2
Specification of NF and UF membranes

Parameter	TFC-SR3	TS40	GHSP
Manufacturer[a]	Koch	TriSep	GE Osmonics
Pore size[a] (MWCO)	200	200	1,000
pH range at 25°C[a]	4–10	2–11	2–11
Standard pressure[a] (bar)	NR	2–14	NR
Contact angle[b] (°)	46	28	68

Note: NR—Not reported.
[a]Information obtained from manufacturer.
[b]Value obtained from experimental measurement.

(Oberkochen, Germany). The instrument was equipped with an energy dispersive X-ray analysis system to identify components that were filtered by the membranes. Attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR) was used to characterize the functional group of the clean NF and UF membranes. The clean membrane coupon was wetted for few hours and dried in a desiccator to avoid interferences of preservatives effects before use for analysis by ATR technique with a Nicolet 6700 FTIR spectrometer (Thermo Scientific, USA). The membrane pure water permeability, L_p was determined by measuring at operating pressure range of 1–5 bar using ultra-pure water at room temperature. Membranes were immersed in ultra-pure water and kept overnight before compacted at 5 bar for 30–45 min prior to use.

2.3. Membrane permeation test

Permeation experiments were performed to investigate the ability of NF and UF membranes based on permeability, flux, and rejection using ultra pure water and samples of groundwater. Ultra pure water with conductivity less than 1 μS/cm were used for determination of pure water permeability. Natural groundwater was used to measure removal efficiency of organic and inorganic constituents in the aim to reach drinking water standard. Salts solution were prepared using NaCl, Na_2SO_4, and $MgCl_2$ which were obtained from Merck with purity for all of them above 99%.

The performance of membranes was conducted using a bench-scale stirred cell separation unit. The setup comprises a nitrogen gas tank, 2000 mL reservoir tank, 300 mL stainless steel stirred cell, and a precision balance (Sartorious AG, Germany, Model AX6202) connected to a data acquisition personal computer. The stirred cell (Sterlitech Corporation, WA, Model HP4750) that houses a 49 mm diameter flat membrane sheet with an effective area of 14.6 cm^2. All membranes were soaked in ultra-pure water overnight before used in order to remove preservatives, and the soaking step was considered as a wetting process for the membrane. The wetted flat sheet membrane was placed at the bottom of a dead-end stirred cell which was supported by a stainless steel porous plate. Then, compaction of membrane was conducted for 30–45 min by pressurizing the stirred cell with nitrogen gas at 5 bar without stirring. After compaction, the pure water permeability test was conducted and the flux was measured based on Eq. (1). The pure water permeability was determined by measuring the slope of a linear plot of pure water flux against applied pressures. A sample of feed solution was then placed into the stirred cell to further determine either flux or rejection according to Eqs. (2) and (3). Filtration test were conducted for 2–3 h or by collection of minimum permeate volume at least 50 mL. For this test, 200 mL of feed solution was placed into the stirred cell and applied pressure were supplied in the range from 1 to 5 bar with fixed stirring rate at 500 rpm for all experiments.

The salts rejection performances of all membranes were checked using 1,000 ppm salt solution at various applied pressures (1–5 bar). Whereas for natural groundwater, the feed solution was used after it has reached room temperature and no changes have been made on its characteristics. A minimum volume of 50 mL of permeate was collected for further analysis on flux, rejection, and concentration. The speed of magnetic stirring bar was kept constant at 500 rpm throughout all experiment. The applied pressure during permeation tests ranged from 1 to 5 bar. The removal efficiency of all membranes at one level of applied pressure was set at 2 bar by analyzing the following physico-chemical parameters: turbidity, conductivity, pH, total dissolved solids (TDS), color, and inorganic constituents (Fe and Mn concentration in permeate).

Pure water flux was calculated by the following Eq. (1):

$$J_w = \frac{Q}{A\Delta t} \qquad (1)$$

where J_w is pure water flux (L h^{-1} m^{-2}), Q is amount of water collected (L) for Δt (h) which is time duration using a membrane coupon with area A (m^2):

The flux of sample of feed solution was measured by the following Eq. (2):

$$J_w = L_p(\Delta P - \Delta\pi) \qquad (2)$$

where J is the sample flux (L h^{-1} m^{-2}), as a function of permeability, L_p (L h^{-1} m^{-2} bar^{-1}) and applied transmembrane pressure, ΔP (bar) taking the osmotic pressure difference between feed and permeate, $\Delta\pi$ (bar) into account.

The rejection of sample of feed solution and the removal efficiency of NF and UF membranes during the filtration was measured by Eq. (3):

$$R_o = \left(\frac{1 - C_p}{C_w}\right) \times 100\% \qquad (3)$$

where R_o is the observed rejection and C_p and C_w are the concentration of permeate and feed, respectively.

2.4. Sample analyses

The collected permeate after separation process was checked for water quality analysis in identifying the best operating variables to meet the drinking water standards. Physico-chemical parameters were measured to investigate efficiency of membranes. Conductivity, pH, and TDS were measured using Hanna Instrument HI2550, whereas turbidity was analyzed by using Turbidimeter (HA 2100AN). Color, Fe, and Mn in permeate were detected by using Spectrophotometer (HACH, Model DR3900). All parameters were analyzed according to the APHA standard methods.

3. Results and discussion

3.1. Membrane hydrophobicity

The properties of NF and UF membranes with respect to the surface hydrophobicity of each selected membrane was determined based on the contact angle between pure water drop and the surface of clean membrane using the sessile drop method. Hydrophobicity of a membrane is usually expressed in terms of a contact angle (θ) which is a measurement of wettability of the membrane. Contact angle of each membrane used for this study are as shown in Fig. 1 Among these membranes, TS-40 was found to be the most hydrophilic and expected to provide highest water flux among the studied membranes. The contact angle of GHSP membrane was more than 60˚ and therefore, it was characterized as hydrophobic.

Hydrophilic membranes are preferable in industrial application such as water treatment process [12]. This is due to the ability to achieve higher production rate and low fouling propensity while improving the quality of water that is treated by the membrane separation processes. Higher flux and low operating pressure of NF make the membrane more feasible and widely used in drinking water industry. The findings of contact angle of the selected membranes in this study revealed that both NF membranes (TS40 and TFC-SR3) are suitable for further application in treating groundwater. However, the potential of both membranes in rejecting contaminants and meeting the drinking water standard should be the main priority. Results of contact angle measurement for TFC-SR3 was detected consistent with the reported data by De Munari et al. [13]. The reported contact angle in their study was determined to be 44˚ that was measured using the sessile drop method.

3.2. Membrane structure morphologies

The membrane structure morphologies for clean NF and UF membranes were investigated by images obtained using the field emission scanning electron microscopy (FESEM) as described in earlier section. Visualization of surface morphological membrane characteristic and cross-sectional images are as presented in Figs. 2 and 3, respectively. The surface images show that all membranes are having uniform distribution and smooth surface morphologies. Observation on the cross-sectional images illustrated that such morphologies are typically from one of two types, a thin-film layer or selective layer and supporter layer. These results are consistent with Alzahrani et al. [14] membrane morphology study using NF1 membrane. All membranes in this work were characterized as thin film composite (TFC) membrane. For commercial TFC membranes, Idil Mouhoumed et al. [15] reported that they were constructed by active layer in polyamide on polysulfone intermediate layer and a polyester support layer. The active layers of TFC-SR3 membranes are made of semi-aromatic polyamide obtained by interfacial polymerization between trimesoyl chloride and piperazine.

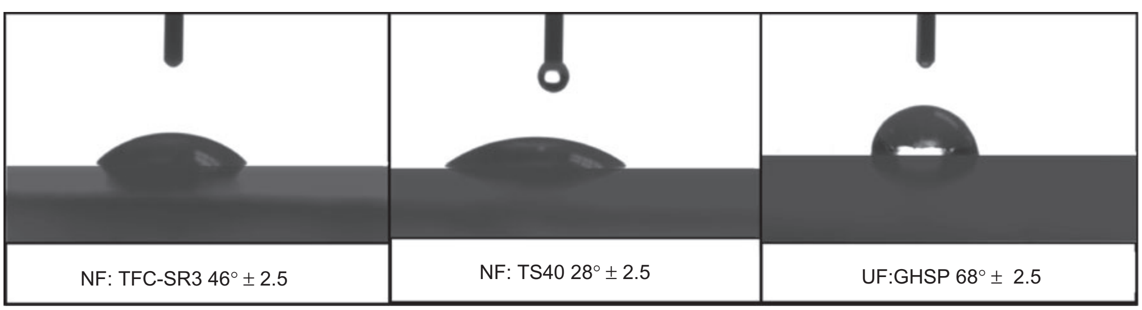

Fig. 1. Water drop contact angle θ° as a function of membrane surface hydrophilicity.

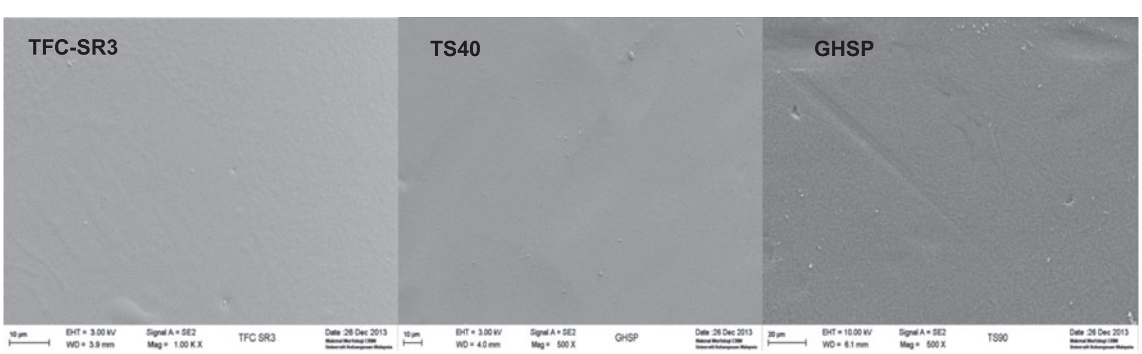

Fig. 2. FESEM images of the membrane surfaces of clean NF and UF membranes.

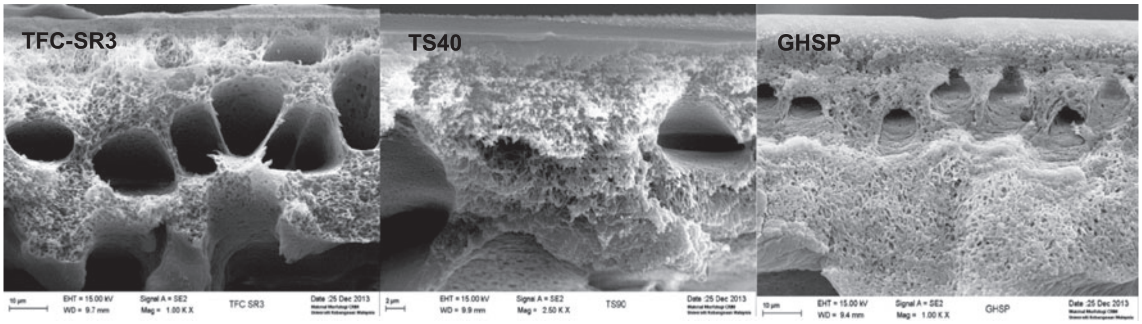

Fig. 3. FESEM images of the cross-sectional morphologies of clean NF and UF membranes.

3.3. Functional group analysis

The ATR-FTIR spectra of clean TFC-SR3, TS40, and GHSP membranes are presented in Fig. 4 for wave numbers ranging from 400 to 4,000 cm^{-1}. The three spectra are almost similar for wave numbers between 400 and ~1,600 cm^{-1}. Due to relatively deep penetration depth of the signal, the active layer skin were probed for further determination of functional group for all membranes. The spectra of all clean membranes showed the standard polyamide ATR-FTIR spectra. The peak around 1,600 cm^{-1} shows the Amide I group, Amide III (γ) has a peak at 1,249 cm^{-1}, and Amide VI (α) shows a peak at 560 cm^{-1}. These results confirmed that active layer for all tested membranes in this study were made of polyamide and congruent with the reported studies by Idil Mouhoumed et al. [15]. While, peaks between 1,100 and 1,600 cm^{-1} attributed to the polysulfone intermediate layers [16].

As mentioned earlier, the spectra are identical for wave numbers lower than 1,600 cm^{-1} which confirms that the same chemical functions were present in the three membranes. However, slight differences among these membranes appeared for wave numbers higher than 2,300 cm^{-1}. Hydrogen bonded N–H shows a stretching vibration and broad peak around 3,319 cm^{-1}. For TFC-SR3 membrane, the overlap of the N–H stretching band of amide groups and that of the O–H stretching band of carboxylic acid functions resulting from the incomplete crosslinking of the polyamide skin layer leads to an additional shoulder peak at 3,500 cm^{-1}. The peak around 1,400, 700, and 2,944 cm^{-1} shows CH2 groups of the polyamide. The similar spectra of the three membranes were congruent with their similar polyamide construction.

3.4. Pure water permeability

Pure water permeability is another important characteristic of a membrane in order to identify its capability for water uptake. The pure water permeability of the NF and UF membranes was obtained from the slope of a plot of flux against pressure. It was found that the pure water flux for all membranes were increased linearly with the applied pressure as

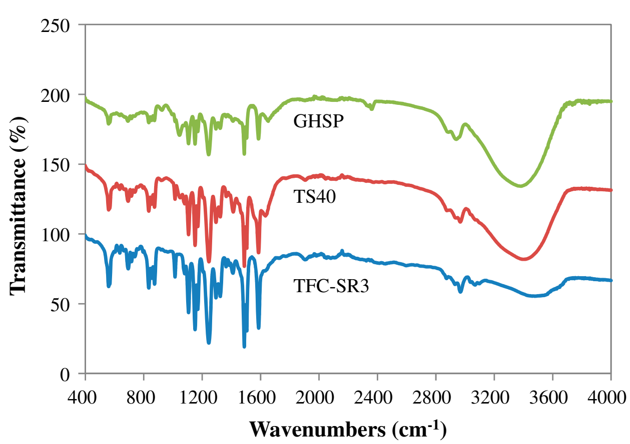

Fig. 4. FTIR spectra of clean NF (TFC-SR3 and TS40) and UF (GHSP) membranes.

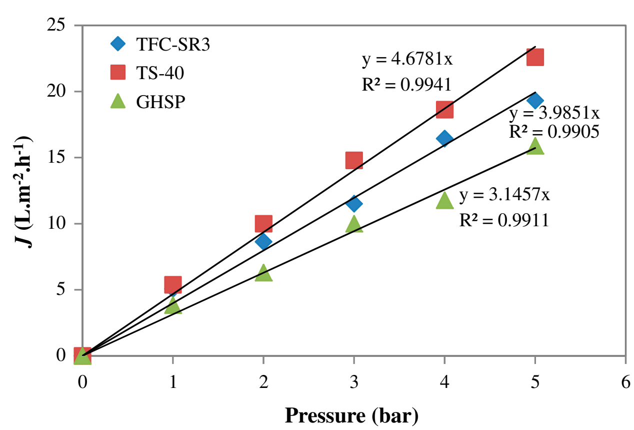

Fig. 5. Pure water flux of NF and UF membranes.

shown in Fig. 5. Pure water flux using each membranes was calculated by using Eq. (1) as mentioned in the earlier section. A line correlation was obtained with high coefficients (R^2) for each types of membranes which is more than 0.99. Results showed that both NF membranes (TS40 and TFC-SR3) exhibited higher permeability (4.68 and 3.99 $L\,m^{-2}\,h^{-1}\,bar^{-1}$) than UF membrane (3.15 $L\,m^{-2}\,h^{-1}\,bar^{-1}$). Therefore, NF membranes were expected to have higher flux than the UF membrane and these findings were concurrent with their contact angles. Results of pure water permeability for NF membranes in this study (TFC-SR3 and TS40) are consistent with Artug and Hapke [17] using NF2 and NF270. Both membranes have similarities with TFC-SR3 and TS40 based on the membrane materials. They were made of polypiperazine amide (PPA) and polyamide (PA), respectively. Higher contact angle was reported for NF2 in comparison to NF270 which explains that PPA membrane contributed lower permeability than PA membrane.

3.5. Rejection of single salts

In this study, the selected membranes were tested to identify their characteristics in terms of rejection in the presence of single salt. Three different types of salts were used to investigate the ability of membranes in rejecting NaCl, Na_2SO_4, and $MgCl_2$. These salts were synthesized in order to measure and reveal their rejection mechanism using the commercial polymeric NF and UF membranes. Rejection measurements of membranes with charged solutions provide information about selective character of the membrane, and the charge of membrane will be a function of the measured rejection. Results from the rejection measurements of charged solutes can be considered as performance parameters since they give direct information on the performance of membranes in a natural environment.

In this performance test, results were interpreted in terms of observed rejection as measured using Eq. (3). Salt rejection measurements with NaCl, Na_2SO_4, and $MgCl_2$ were maintained at approximately 1,000 ppm at a pressure applied of 5 bar. In the case of NF membranes, results for salt rejection by TFC-SR3 and TS40 membrane were depicted in Fig. 6(A) and (B), respectively . Results indicated that both NF membranes demonstrated the lowest rejection for NaCl and the highest rejection for Na_2SO_4. Both membranes showed the following salt rejection sequence: R (Na_2SO_4) > R ($MgCl_2$) > R (NaCl) as presented in Table 3. These results indicated that they were classified as amphoteric membrane. This type of NF membranes, neither surface charge nor size effects fully determined the separation mechanism [18].

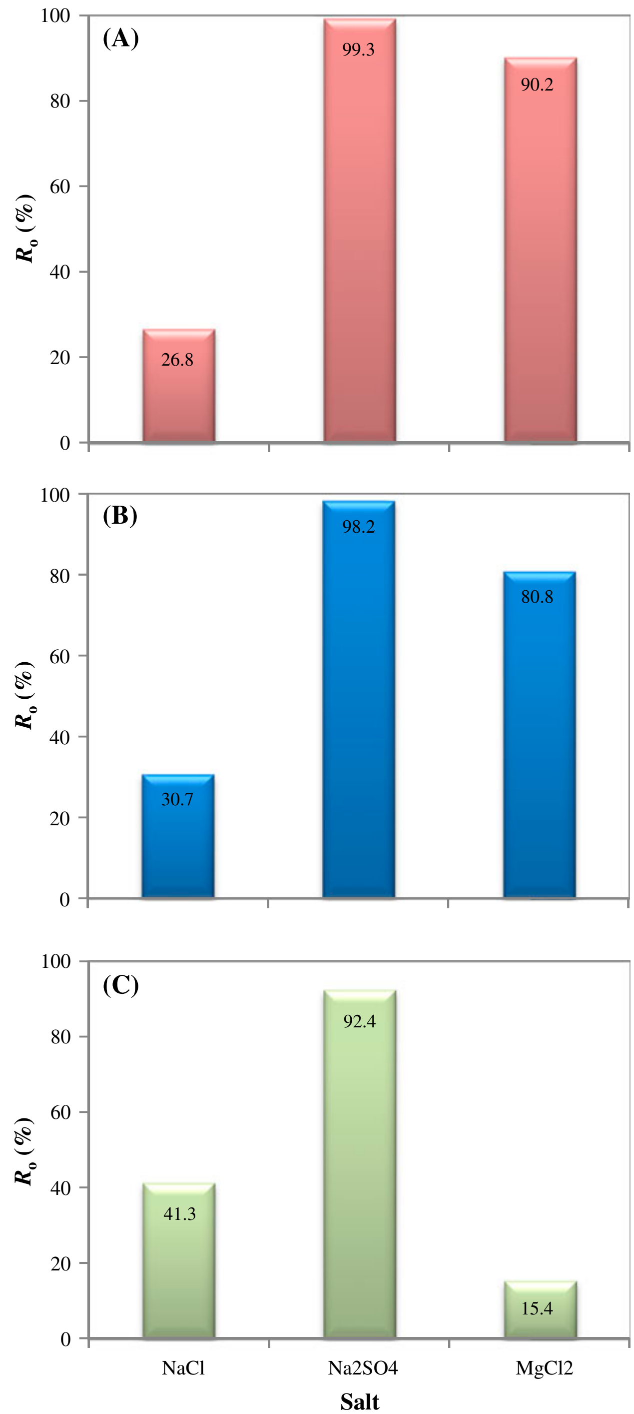

Fig. 6. Rejection of salt solutions (NaCl, Na_2SO_4, and $MgCl_2$) by (A) TFC-SR3; (B) TS40; and (C) GHSP membranes at operating condition: 1,000 ppm salt, 5.0 bar, 25˚C.

Membranes with this behavior were determined by the differences in diffusion coefficients between salts. In this case, diffusion seems to be an important transport mechanism as the order of the diffusion coefficients is inversely proportional to the salt retention

Table 3
Diffusion coefficient of salts and the order of single salt rejection by NF and UF membranes

Membrane	Order of single salt rejection	Salt	D_i (10^{-9} m^2/s)
TFC-SR3	$Na_2SO_4 > MgCl_2 > NaCl$	NaCl	1.61
TS40	$Na_2SO_4 > MgCl_2 > NaCl$	$MgCl_2$	1.25
GHSP	$Na_2SO_4 > NaCl > MgCl_2$	Na_2SO_4	1.23

Note: D_i, Diffusion coefficient of salts at 25˚C [19].

sequence as depicted in Table 3 [19]. The salt with the lowest diffusion coefficient shows the highest rejection and vise versa.

Fig. 6(C) shows results for salt rejection measurement using UF membrane. Results presented that GHSP membrane demonstrated the lowest rejection for $MgCl_2$ and the highest rejection for Na_2SO_4. This membrane showed the following salt rejection sequence: R (Na_2SO_4) > R (NaCl) > R ($MgCl_2$). It was reported that this sequence of single salt rejection is typical for a negatively charged membrane. These results were in accordance with the Donnan exclusion theory. Therefore, this finding indicated that the salts retention were determined by charge effect for the GHSP membrane.

3.6. Removal efficiency of organic and inorganic constituents in groundwater

In order to investigate the potential of NF and UF membranes as a medium for treating groundwater, a minimum volume at 50 mL of permeate should be collected for each filtration experiment. Permeate was tested by conducting a primary assessment of their removal efficiency for conductivity, color, turbidity, and metal content at low applied pressure of 2 bar. These parameters were chosen to represent organic and inorganic constituent of such water because the current available guidelines for treating natural water resources as potable water suggest to meeting the following requirement [4]: to satisfy drinking water standards, pH value must be in the range of 6.5–9.0, turbidity should not exceed than 5 NTU, color residue has to be less than 15 PtCo, TDS should not exceed 1,000 mg L^{-1}, and metal content of Fe and Mn must be below than 0.3 and 0.1 mg L^{-1}, respectively. Therefore, a primary assessment of the NF and UF membranes' potential for removal efficiency on the parameters listed as in Table 4 were conducted to test their feasibility in treating groundwater for potable water production.

The set of data in this table were compared with the international drinking water standard [4]. This table provided data on the water quality assessment for pre and post-filtration using the hydrophilic NF and tight UF membranes. Results show that water quality produced by NF membranes especially by using TFC-SR3 was much better than UF membrane. Results also given in terms of rejection for organic and inorganic as presented in Fig. 7. For conductivity, that represents the level of dissolved salts in water sample, filtration with NF and UF membranes yielded final conductivity values of 21.8, 24.3, and 29.3 μS/cm, respectively. These values were below the original conductivity in feed water at 50.5 μS/cm. Rejection of conductivity were in the range of 42–57% for all membranes as depicted in Fig. 7(A). Filtration using NF membranes reduced color from 53 to 2 and 3 PtCo

Table 4
Primary assessment of groundwater quality

			After filtration		
Test parameter	Units	Before filtration	TFC-SR3	TS40	GHSP
pH	–	5.5	7.3	6.5	6.2
Conductivity	μS/cm	50.5	21.8	24.3	29.3
Color	PtCo	53.0	2.0	3.0	12.0
Turbidity	NTU	14.0	0.16	0.25	0.35
TDS	mg L^{-1}	25.0	10.6	12.8	14.7
Fe	mg L^{-1}	7.2	0.18	0.61	0.46
Mn	mg L^{-1}	0.8	0.10	0.29	0.78

Note: Operating condition: p = 2.0 bar, T = 25˚C.

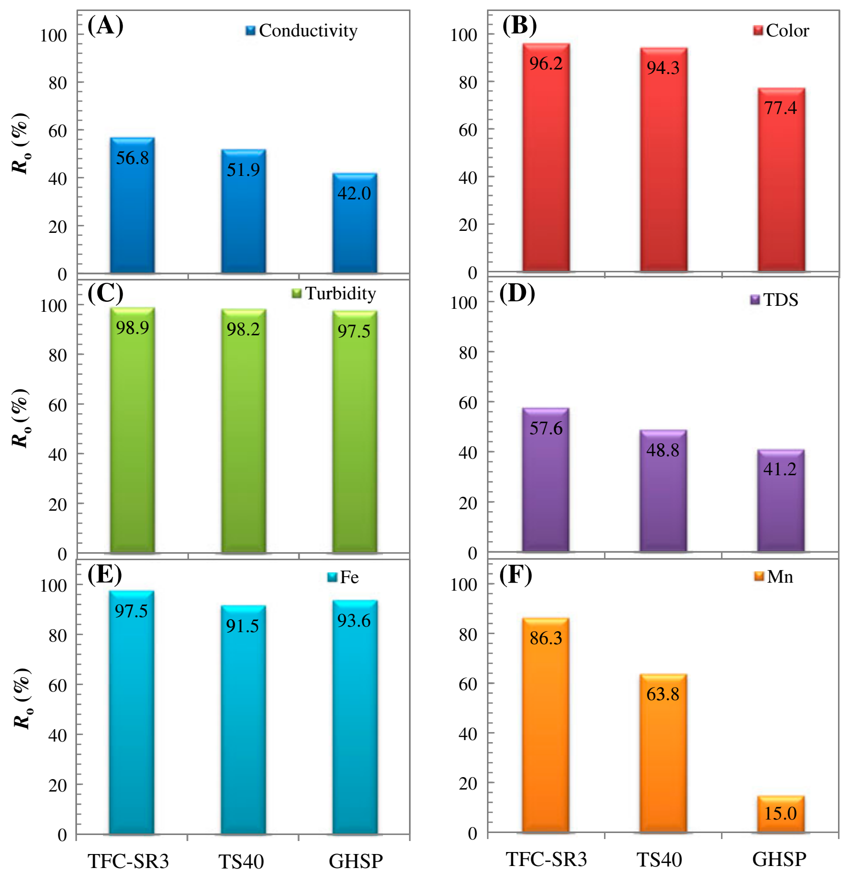

Fig. 7. Rejection of (A) conductivity; (B) color; (C) turbidity; (D) total dissolved solids (TDS); (E) Fe; and (F) Mn from natural groundwater using NF and UF membranes.

while using UF membrane reduced to 12 PtCo. Therefore, rejection for color using NF membranes had achieved more than 90% whereas by using UF membrane was 77% as depicted in Fig. 7(B).

Fig. 7(C) and (D) presented results for turbidity and TDS rejection using NF and UF membranes. The NF membranes achieved turbidity removal at 98.9% and 98.2% whereas for UF membrane at 97.5% from feedwater with 14 NTU. Initial TDS of groundwater sample at 25 mgL^{-1} was removed by 57.6 and 48.8% using NF membranes while exactly 41.2% rejection via UF membrane. As for inorganic constituents, only TFC-SR3 managed to reduce Fe level of 7.2 $mg\,L^{-1}$ in the raw water to 0.18 $mg\,L^{-1}$ that is far below the drinking water standard. The same type of membrane also had succesfully reduced Mn to 0.10 $mg\,L^{-1}$ from 0.80 $mg\,L^{-1}$ in the pre-filtration sample. However, TS40 and GHSP membrane were unable to remove Fe and Mn in order to achieve the WHO drinking water standard. All results of pre and post-filtration are presented in Table 4. Based on rejection results presented in Fig. 7(E) and (F), removal of Fe was more competent than Mn for all membranes used. Therefore, it could be concluded that TFC-SR3 membrane was the most efficient to produce potable water from groundwater resources.

4. Conclusion

Three commercially available NF and UF membranes were characterized and tested to investigate their ability in treating groundwater for potable water resources. Results of characterization showed that both NF membranes were hydrophilic and UF was hydrophobic. Morphological characterization found that all membranes consisted of thin film composite structure with two layers. The functional group analysis proved that all of them were polyamide-based membranes. From the quality and availability observations, natural groundwater in Malaysia has the potential to be treated for drinking water resources by using both hydrophilic NF membranes. The tight UF membrane was unable to eliminate both dissolved inorganics constituents (Fe and Mn); however, it has the potential to be used as pre-treatment process in treating groundwater. TFC-SR3 membrane is the most preferable, as it has achieved drinking water standards with high rejection of Fe and Mn at low applied pressure. The effectiveness of TS-40 membrane was essentially limited by the low applied pressure and required further studies to improve the rejection performance. The findings on NF-treated water quality substantiated the possibility of utilizing groundwater as potable water resources in future.

Acknowledgment

The authors would like to thank the Universiti Kebangsaan Malaysia by the grant ICONIC-2013-02 for financial supports. Additionally, the first author is gratefully wished special thanks to the National Defence University of Malaysia for funding the scholarship.

References

[1] L.H. Chu, Groundwater Utilization and Management in Malaysia, in: Thematatic Session Geo-Environment Delta Groundwater Management East Southeast Asia, CCOP Annual Session, Tsukuba, 2004, pp. 83–93.
[2] H. Jusoh, N. Sapari, R.Z.R. Azie, Removal of iron from groundwater by sulfide precipitation, World Acad. Sci. Eng. Technol. (2011) 652–658.
[3] A. Khalik, V.S. Praptowidodo, Nanofiltration for drinking water production from deep well water, Desalination 132 (2000) 287–292.
[4] WHO, Guidelines for drinking-water quality, in: Reccomendations, vol. 1, third ed., World Health Organization, Geneva, 2008, pp. 390–399.
[5] B. Van der Bruggen, C. Vandecasteele, Removal of pollutants from surface water and groundwater by nanofiltration: Overview of possible applications in the drinking water industry, Environ. Pollut. 122 (2003) 435–445.
[6] D.X. Wang, M. Su, Z.Y. Yu, X.L. Wang, M. Ando, T. Shintani, Separation performance of a nanofiltration membrane influenced by species and concentration of ions, Desalination 175 (2005) 219–225.
[7] R.S. Harisha, K.M. Hosamani, R.S. Keri, S.K. Nataraj, T.M. Aminabhavi, Arsenic removal from drinking water using thin film composite nanofiltration membrane, Desalination 252 (2010) 75–80.
[8] D. Ellis, C. Bouchard, G. Lantagne, Removal of iron and manganese from groundwater by oxidation and microfiltration, Desalination 130 (2000) 255–264.
[9] K.H. Choo, H. Lee, S.J. Choi, Iron and manganese removal and membrane fouling during UF in conjunction with prechlorination for drinking water treatment, J. Memb. Sci. 267 (2005) 18–26.
[10] J.H. Potgieter, R.I. Mccrindle, Z. Sihlali, R. Schwarzer, N. Basson, Removal of iron and manganese from water with a high organic carbon loading. Part I: The effect of various coagulants, Water, Air Soil Pollut. 162 (2005) 49–59.
[11] N. Hilal, H. Al-Zoubi, N.A. Darwish, A.W. Mohammad, M. Abu, Arabi, A comprehensive review of nanofiltration membranes: Treatment, pretreatment, modelling, and atomic force microscopy, Desalination 170 (2004) 281–308.
[12] A.L. Ahmad, B.S. Ooi, A.W. Mohammad, J.P. Choudhury, Development of a highly hydrophilic nanofiltration membrane for desalination and water treatment, Desalination 168 (2004) 215–221.
[13] A. De Munari, A.J.C. Semiao, B. Antizar-Ladislao, Retention of pesticide Endosulfan by nanofiltration: Influence of organic matter–pesticide complexation and solute–membrane interactions, Water Res. 47 (2013) 3484–3496.
[14] S. Alzahrani, A.W. Mohammad, P. Abdullah, O. Jaafar, Potential tertiary treatment of produced water using highly hydrophilic nanofiltration and reverse osmosis membranes, J. Environ. Chem. Eng. 1 (2013) 1341–1349.
[15] E. Idil Mouhoumed, A. Szymczyk, A. Schäfer, L. Paugam, Y.H. La, Physico-chemical characterization of polyamide NF/RO membranes: Insight from streaming current measurements, J. Memb. Sci. 461 (2014) 130–138.
[16] C.Y. Tang, Y.N. Kwon, J.O. Leckie, Effect of membrane chemistry and coating layer on physiochemical properties of thin film composite polyamide RO and NF membranes, Desalination 242 (2009) 168–182.
[17] G. Artuğ, J. Hapke, Characterization of nanofiltration membranes by their morphology, charge and filtration performance parameters, Desalination 200 (2006) 178–180.
[18] J.M.M. Peeters, J.P. Boom, M.H.V. Mulder, H. Strathmann, Retention measurements of nanofiltration membranes with electrolyte solutions, J. Memb. Sci. 145 (1998) 199–209.
[19] J. Schaep, B. Van der Bruggen, C. Vandecasteele, D. Wilms, Influence of ion size and charge in nanofiltration, Sep. Purif. Technol. 14 (1998) 155–162.