

Groundwater and sea water desalination using thin film composite membranes (Quseir city, Egypt, case study)

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ABSTRACT

The possibility of producing drinking water from brackish, saline groundwater and sea water samples collected from Quseir city, Red Sea, Egypt using Lab prepared thin film composite (TFC) membrane was studied. The obtained results showed that the total dissolved solids (TDS) decreased from 2971.68 to 362.1 mg/l, 9062.53 to 591.79 mg/l and from 44703.58 to 5730.9 mg/l, in brackish, saline and sea water samples, with salt rejection percent of 87.81, 93.47 and 87.18 % and water flux of 27.77, 94.44 and 33.33 L/m².h at 20, 35 and 40 bars, respectively. The effect of applied pressure and feed concentration on both water flux and salt rejection of membrane was also considered. The cations and anions rejection (R_s , %) showed that the divalent cations and anions are more rejected than the monovalent ones. The desalted water produced from desalination process of brackish and saline groundwater samples in one stage of operation is acceptable for drinking according to WHO and Egyptian guidelines. So, we can conclude that the membranes prepared at our Labs are more preferable for brackish water desalination.

Key words: TFC membrane; brackish and saline groundwater; sea water; desalination.

Introduction

Water is the source of life, and is essential for social and economic development. Water shortage has recently become a serious problem worldwide. Although 75% of the earth's surface is water, 97.5% of it is in oceans and is considered undrinkable without proper processing due to its high salinity. Only the remaining small 2.5% of the earth's water is considered freshwater. However, only 0.3% of the freshwater in lakes and rivers is accessible, while the remaining freshwater is deep underground or in the form of snow and ice (United Nation, 2009).

Egypt is facing water scarcity (especially in coastal areas) as a result of over-population, industrialization and agricultural expansion and increasing conflict of the current Egyptian-Ethiopian's dam problem. The rapid development of tourist resorts along the western Red Sea coast, which has exhausted water demand for substantial mining operations. This has led to a widespread need for the development and management of regional water resources. The investigated area lies within the central part of Eastern Desert; it extends parallel to the western coast of the red sea for about 120 km with a width varying between 40 and 80 km inland wards. The water resources in this area can be classified into the following categories: i) Underground water, ii) Potable water transported by pipeline and iii) Desalinated water.

For sustainable development in such region, there is a need to establish desalination plants to provide the necessary water. So, in this study, thin film composites (TFC) reverse osmosis (RO) membranes will be prepared in an attempt to desalt the brackish and saline water. Water desalination can be accomplished by thermal and membrane processes of which the membrane processes are subdivided into: (i) Reverse osmosis (RO) (ii) Electrodialysis and (iii) Nanofiltration. The two processes of reverse osmosis and the multi-stage flash distillation processes are the most commercial in producing of drinking water from brackish or sea water (Al-Sofi, 2001).

It is known that, the natural water contain both positively (cations) and negatively (anions) charged ions. So, when these cations and anions comes in contact with the negatively charged TFC membranes, the cations will be attracted to the membrane surface, so their concentration in the membrane is greater than in bulk solution and vice versa in case of anions. This ions shift makes an electrical potential at the boundary between the membrane and the solution (Donnan potential). According to Donnan theory the salt rejection is mainly depend on the anion rejection.

The rejection mechanism of TFC membrane for charged compounds (ions in natural ground and sea waters) are more complicated because both cations and anions are transported through the membrane, it is not clear how a single size parameter can be calculated. Also more than one cation can be accompanied by one anion and vice versa, depending on the ion valences. However, some mechanisms such as the role of size exclusion,

electrostatic interactions and the membrane charge along the surface and through the pores may be used to explain the ions rejection (Teixeira *et al.*, 2005 and Childress *et al.*, 2000).

The overall goal of this study is to prepare thin film composite (TFC) membrane to be used it in the desalination process of different samples; brackish & saline groundwaters and sea water collected from the study area.

Materials and Methods

Materials:

Polysulfone beds (Udel P 3500 LCD MP7), 1, 3, 5-Benzenetricarbonyl trichloride (TMC) (>98%), m-phenylenediamine (MPD) (> 99%), triethylamine (TEA), camphor sulphonic acid (CSA) and sodium lauryl sulphate (SLS) were purchased from Sigma–Aldrich and used as received.

Methods:

Preparation of polysulfone support (Ps) membrane:

PS casting solution was prepared by phase inversion method (Huan *et al.*, 2009), dissolving 15wt. % PS bead, in N,N-Dimethylacetamide as a suitable solvent at 70-80°C with constant stirring until homogenous solution was obtained. After that, the solution was casted on a flat and horizontal glass plate. The membrane was allowed to dry and the solvent was slowly evaporated in air for 30 sec. The casting (at room temp.) and evaporation processes were followed by precipitation in coagulation (water bath). The membranes were removed from the coagulation bath and washed thoroughly with distilled water to remove residual solvents and kept wet until used.

Preparation of thin film composite membrane:

TFC membranes were synthesized via interfacial polymerization technique (Cadotte *et al.*, 1980 & Cadotte, 1981 and Sanchuan *et al.*, 2009), using MPD aqueous solution and TMC in hexane solution. The aqueous-MPD solution (2 %) containing additives (TEA: CSA: SLS in ratio of 2:4:1 w/v %) was poured onto the top surface of the supporting PS layer and allowed to soak for 2 minutes. Excess solution was drained off the surface using soft rubber until no excess MPD droplets exist. Organic solution of TMC (0.1 %) was poured onto PS membrane saturated with MPD. After 60 seconds, the excess organic solution was removed off the surface, the reaction between MPD and TMC resulted in the formation of an ultra- thin layer of PA over the surface of PS support layer. Finally, the resulting TFC membrane was cured in an oven at 85 °C for 10 minutes to attain the desired stability of the formed structure. The membranes were thoroughly washed and kept in distilled water until carrying out applied studies.

Water sampling and analysis:

Brackish and saline groundwater samples as well as sea water sample were collected in clean polyethylene bottle from Quseir city, Red sea, Egypt, Figure (1) and subjected to analysis of physical and chemical properties of water samples. Electrical conductance (EC) was measured by EC meter Model LF 538, WTW, USA and expressed in micromhos per centimeter ($\mu\text{S}/\text{cm}$) at 25 °C, and pH value was measured by 3320 pH meter (Jenway, UK). Total dissolved salts (TDS) and soluble Ca^{2+} , Mg^{2+} , Na^+ , K^+ , CO_3^- , HCO_3^- , SO_4^- and Cl^- ions concentration were determined following to the methods adopted by American Society for Testing and Materials (ASTM, 2002).

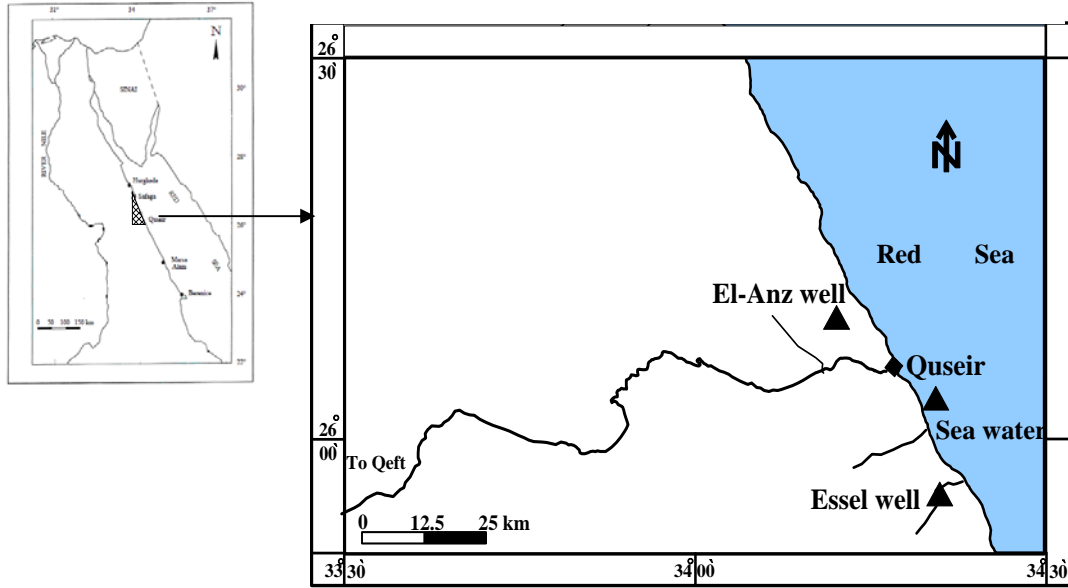


Fig. 1: Well location map of different samples

RO performance:

Reverse osmosis properties, salt rejection (R_s %) and water flux (J_w) of the prepared membranes were measured by laboratory DDS reverse osmosis system, model LAB-M20, manufactured by Alfa Laval Comp., Denmark which consists of stainless steel cylindrical vessel, 20 cm diameter and 70 cm height, with control panel. The effective membrane areas range from 0.036 to 0.72 m² (0.018 m² per membrane). The salt rejection percent (R_s %) was calculated as:

$$R_s (\%) = (C_f - C_p / C_f) \times 100$$

Where C_f and C_p are the concentrations of feed and permeate water (product), respectively. The water flux (J_w) was expressed in weight of the product per unit membrane area during operation time in liter (L/m².h) is calculated as follow;

$$J_w = Q / A \times t$$

Where, Q is water permeates in liter, A is the membrane area in square meter and "t" is the time in hour.

Results and Discussions

Membrane permeability:

The importance of studying the pure water permeability is to reflect the porous structure of the membrane, where the linear dependence of the pure water flux (J_w) on applied pressure indicates unchangeable membrane porosity. On the other hand, if the water flux dependence on pressure deviates from linearity, it indicates the changes in the membrane's porosity (Kosutic *et al.*, 2006). Figure (2) shows the water permeability of TFC membranes at different applied pressures, where the linear relation is obtained indicating evolution of fluxes with membrane pressure thus Darcy's law is valid. This linear behavior is described by a slope which corresponds to ultra pure water permeability ($L_p = 2.729$).

$$J_w = L_p \times \Delta P \quad \text{Darcy's law}$$

Where; J_w is the water flux, L_p is the hydraulic permeability, P is the applied pressure.

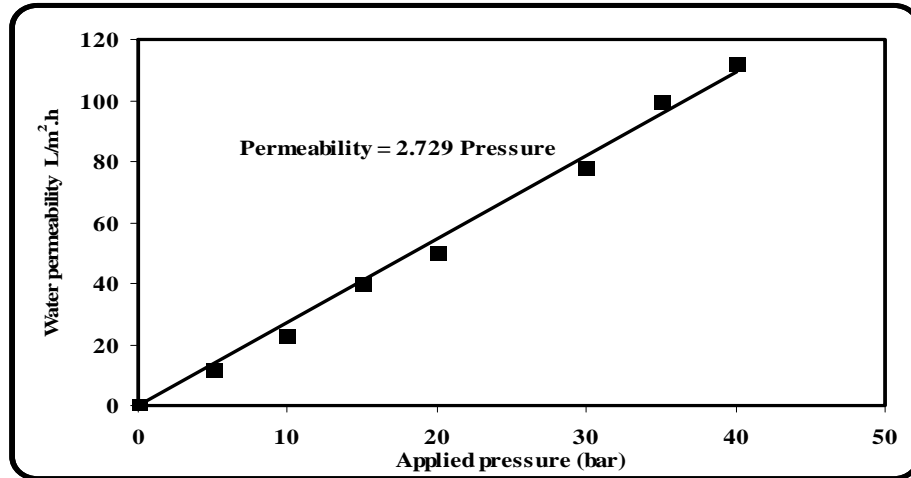


Fig. 2: Water permeability as a function of the applied pressure for TFC membrane.

Effect of applied pressure on membrane performance:

The water flux and salt rejection experiments of TFC membranes were performed with synthetic NaCl solution (TDS=2000 mg/l). Where, both water flux and salt rejection mainly depend on the applied pressure where they increase from 20 to 101.1 L/m².h and from 88.47 to 93.2 %, respectively as applied pressure increases from 15 to 40 bar, Figure (3). Both of water flux and salt rejection mainly depend on the applied pressure. They increase from 20 to 101.1 L/m².h and from 88.47 to 93.2 %, respectively as applied pressure increases from 15 to 40 bars.

The high water flux of the membrane generally indicates a high porosity. On the other hand; the increases of salt rejection can be explained by considering salt transport through the membrane as a result of diffusion and convection, which are due to a concentration and a pressure gradient across the membrane, respectively. At a low pressure, diffusion contributes substantially to the salt transport resulting in a lower salt retention. With increasing pressure, the salt transport by diffusion becomes relatively less important, so that salt retention is higher (Schaep *et al.*, 1999 and Van Gestel, 2002).

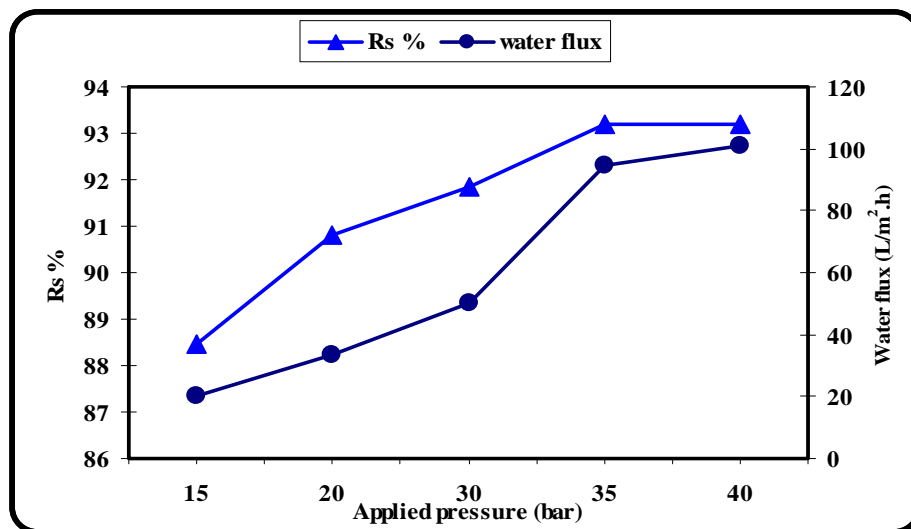


Fig. 3: Water flux and salt rejection as a function of the applied pressure for the TFC membrane.

Brackish & saline groundwater and Sea water desalination:

It is well known in the membrane industry that salt passage through a reverse osmosis membrane is affected by feed water characteristics. So, two groundwater samples (brackish and saline) as well as sea water sample were used as feed solutions for RO unit. In the study area, the brackish and saline groundwater desalination is one of the important tools for meeting water supply needs. Two groundwater samples were selected from high productive wells of wadi Essel and wadi El Anz as well as Red sea water sample to evaluate the prepared flat TFC membrane performance in desalination process. Such water samples were pressurized into RO unit at flow rate 5 l/min and different applied pressures ranges from 10 to 40 bar. All desalted permeated water were collected after about eight hours (stability of the salt rejection and water flux) to be chemically analyzed. The chemical parameters of the feed and product waters for the three samples at different applied pressures before and after desalination process are shown in Table (1).

Table 1: Chemical analysis data of pre-treated and post-treated for brackish & saline groundwater and sea water samples.

Applied pressure	TDS (mg/l)	unit	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Total cations	CO ₃ ⁻	HCO ₃ ⁻	SO ₄ ⁻	Cl ⁻	Total anions
Brackish groundwater sample (Essel well)												
Feed water	2971.68	mg/l	268.8	209.95	525	14	53.88	0.00	262.86	487.5	1335	52.09
		me/l	13.41	17.27	22.84	0.36		0.00	4.3	10.15	37.65	
		%	24.9	32.05	42.39	0.66		0.00	8.25	19.48	72.27	
10 bar	555	mg/l	16.8	14.8	166.2	10.50	9.55	0.00	62.2	75.6	240	9.36
		me/l	0.84	1.22	7.23	0.27		0.00	1.02	1.57	6.77	
		%	8.77	12.74	75.67	2.81		0.00	10.87	16.82	72.32	
15 bar	413.23	mg/l	15.36	11.66	112.88	8.29	6.85	0.00	37.55	57.14	189.13	7.14
		me/l	0.77	0.96	4.91	0.21		0.00	0.61	1.19	5.33	
		%	11.19	14.01	71.7	3.1		0.00	8.6	16.67	74.73	
20 bar	362.1	mg/l	11.52	11.66	98.78	7.62	6.03	0.00	31.29	50	166.88	6.26
		me/l	0.57	0.96	4.3	0.19		0.00	0.51	1.04	4.71	
		%	9.54	15.92	71.31	3.23		0.00	8.18	16.63	75.19	
Saline groundwater sample (Anz well)												
Feed water	9062.53	mg/l	1248	419.9	1466.67	100	163.17	0.00	62.59	1050	4746.6	156.74
		me/l	62.28	34.53	63.8	2.56		0.00	1.02	21.86	133.86	
		%	38.17	21.16	39.1	1.57		0.00	0.65	13.95	85.4	
15 bar	1051.27	mg/l	57.6	29.16	263.4	29.21	17.48	0.00	31.29	100	556.25	18.28
		me/l	2.87	2.4	11.46	0.75		0.00	0.51	2.08	15.69	
		%	16.45	13.72	65.56	4.28		0.00	2.8	11.39	85.81	
20 bar	809.87	mg/l	48	17.5	208.94	28.3	13.65	0.00	25.03	94.12	400.5	13.66
		me/l	2.4	1.44	9.09	0.72		0.00	0.41	1.96	11.29	
		%	17.55	10.54	66.6	5.3		0.00	3.00	14.34	82.66	
30 bar	706.21	mg/l	48	14.58	183.35	26.52	12.25	0.00	25.03	87.5	333.75	11.64
		me/l	2.4	1.2	7.98	0.68		0.00	0.41	1.82	9.41	
		%	19.56	9.79	65.12	5.54		0.00	3.52	15.65	80.84	
35 bar	591.7	mg/l	38.4	11.66	144.2	23.89	9.76	0.00	18.78	75	289.25	10.03
		me/l	1.92	0.96	6.27	0.61		0.00	0.31	1.56	8.16	
		%	19.63	9.83	64.27	6.26		0.00	3.06	15.58	81.36	
Sea water sample												
Feed water	44678.96	mg/l	422.4	1959.55	14000	350	800.18	0.00	194.02	3375	24475	763.63
		me/l	21.08	161.15	609	8.95		0.00	3.17	70.27	690.2	
		%	2.63	20.14	76.11	1.12		0.00	0.42	9.2	90.38	
40 bar	5730.71	mg/l	76.8	93.31	1998.40	55	99.84	0.00	62.59	494.4	2981.5	95.39
		me/l	3.83	7.67	86.93	1.41		0.00	1.02	10.29	84.08	
		%	3.84	7.69	87.07	1.41		0.00	1.07	10.79	88.14	

Water flux and salt rejection:

It is obvious that the water flux and salt rejection increased as applied pressure increases from on brackish to saline water while both decreased in sea water sample. The water salinity decreased from 2971.68 to 362.10 mg/l, from 9062.53 to 591.7mg/l and from 44678.96 to 5730.71 mg/l, for brackish, saline and sea water samples, respectively, with salt rejection percent of 87.81, 93.46 and 87.18 %. However, the decreases of J_w of sea water sample to 33.33 L/m².h is due to the low difference between the applied pressure on this extremely saline water and natural osmotic pressure due to high concentration of salts accumulated on the membrane surface that restrict water permeability through the membrane.

Table 2: Comparison between salt rejection and water flux of brackish, saline groundwater and sea water samples.

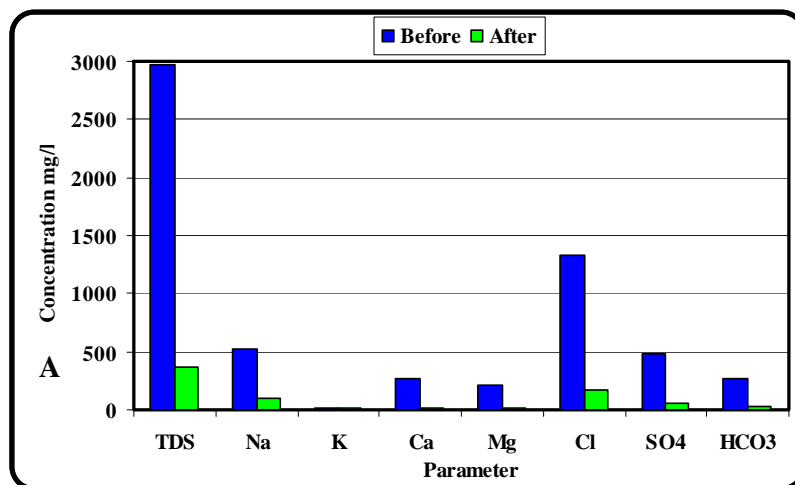
Parameter	Applied pressures (bar)	Osmotic pressure (bar)	Feed TDS (mg/l)	Permeate TDS (mg/l)	Rs %	J _w (L/m ² .h)
Brackish water	20	2.09	2971.68	362.1	87.8	27.77
Saline water	35	6.36	9062.53	571.9	93.7	94.44
Sea water	40	35.1	447678.96	5730.71	87.2	33.33

TDS and Ions rejection:

The TDS and different ions present in two groundwater and sea water samples before and after desalination process are shown in Table (1) and Figure (4) where their concentrations decrease with different rejection rate. The rejection rate of TDS using TFC membrane in the desalination processes reach 87.8 %, 93.5 % and 87 % at 20, 35 and 40 bars in brackish, saline and sea water samples, respectively. This high rejection rate is related to the surface characteristic of the membrane; because the surface charges of polyamide TFC membrane is negative due to the presence of carboxylic functional groups at the membrane surface. The electrostatic interaction mechanism takes place between the ions and the membrane surface (Petersen, 1993 and Schaep *et al.*, 1998), so the cations can be adsorbed by cation adsorption and the anions are repelled according to the Donnan exclusion mechanism (Teixeira *et al.*, 2005). Figure (5) shows the rejection percent and sequences of the different ions during the desalination process, where the sequence of cations rejection decreases in orders of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^{+} > \text{K}^{+}$ & $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^{+} > \text{K}^{+}$ and $\text{Mg}^{2+} > \text{Na}^{+} > \text{K}^{+} > \text{Ca}^{2+}$ for brackish, saline and sea water samples, respectively. On the other hand, the anions sequence decreased in the orders $\text{SO}_4^{2-} > \text{HCO}_3^- > \text{Cl}^-$ for brackish water sample and $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$ for saline and sea water samples. The rejection of ions present in feed water can be explained on basis of electrostatic interaction between ions in water and membrane surface charge. From such figure, it is noted that the retention of bivalent ions was higher than that of monovalent ones, except for anions in sea water sample, where Cl^- is more rejected than SO_4^{2-} ions. This can be attributed to difference in diffusivity, hydrated diameters and hydration energy of different ions, Table (3). Based on ions diffusivity and hydration energy, the ion is retained more if it has a smaller diffusivity and higher hydrated diameter and hydration energy (Schaep *et al.*, 2001 and Walha *et al.*, 2007); This is inversely reflected in the rejection sequence. Beside these mechanisms, the SO_4^{2-} and HCO_3^- ions are more rejected than Cl^- in brackish and saline water samples due to higher charge repulsion with negatively charged membrane (Mattaraj *et al.*, 2011). Then chloride must be the lowest retained ion in order to satisfy the electroneutrality requirements.

Table 3: Diffusivity, hydration diameters, hydration energy and salt rejection of the different ions.

Ion	Diffusivity ($10^{-9}\text{m}^2.\text{sec}^{-1}$) (D)	Hydrated diameter, 10^{-12} m (Phillip <i>et al.</i> , 2010)	Hydration energy ($\text{kJ}.\text{mol}^{-1}$) (E_h)	Rs %
Na^{+}	1.333	450	407	81.2
K^{+}	--	300	--	45.5
Mg^{2+}	0.706	800	1921	95.5
Ca^{2+}	0.92	600	1584	94.2
Cl^-	2.032	300	376	87.5
HCO_3^-	1.85	450	--	90.4
SO_4^{2-}	1.065	400	1138	89.7



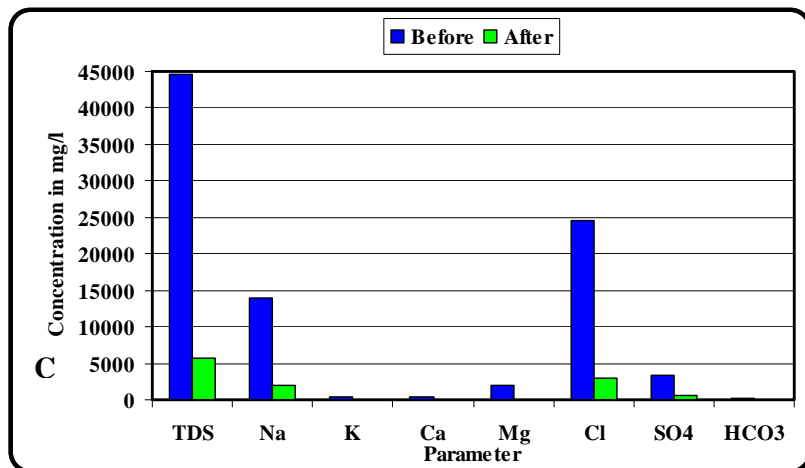
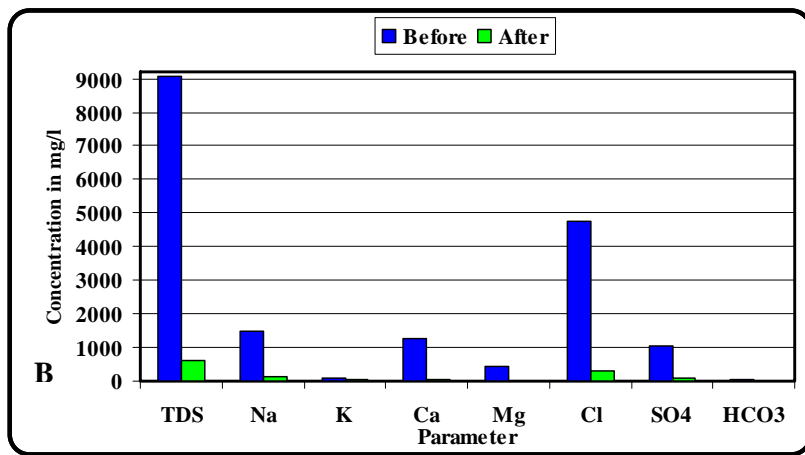
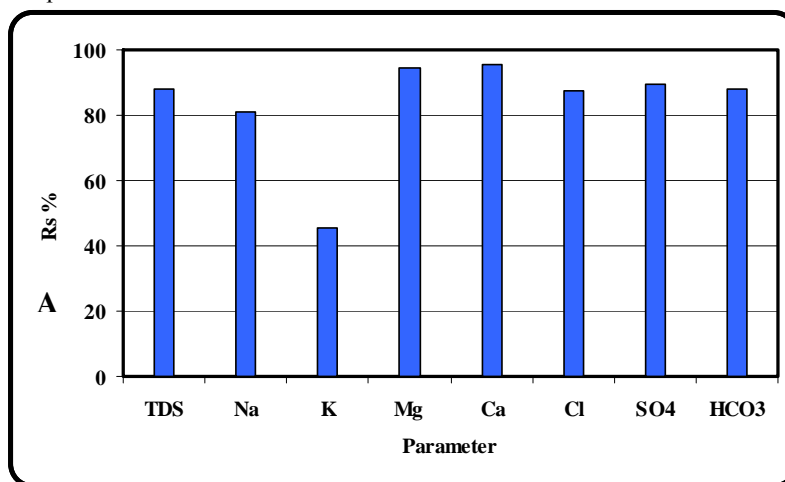


Fig. 4: Salinity and ionic concentrations before and after desalination process of A) brackish, B) saline and C) Sea water samples.



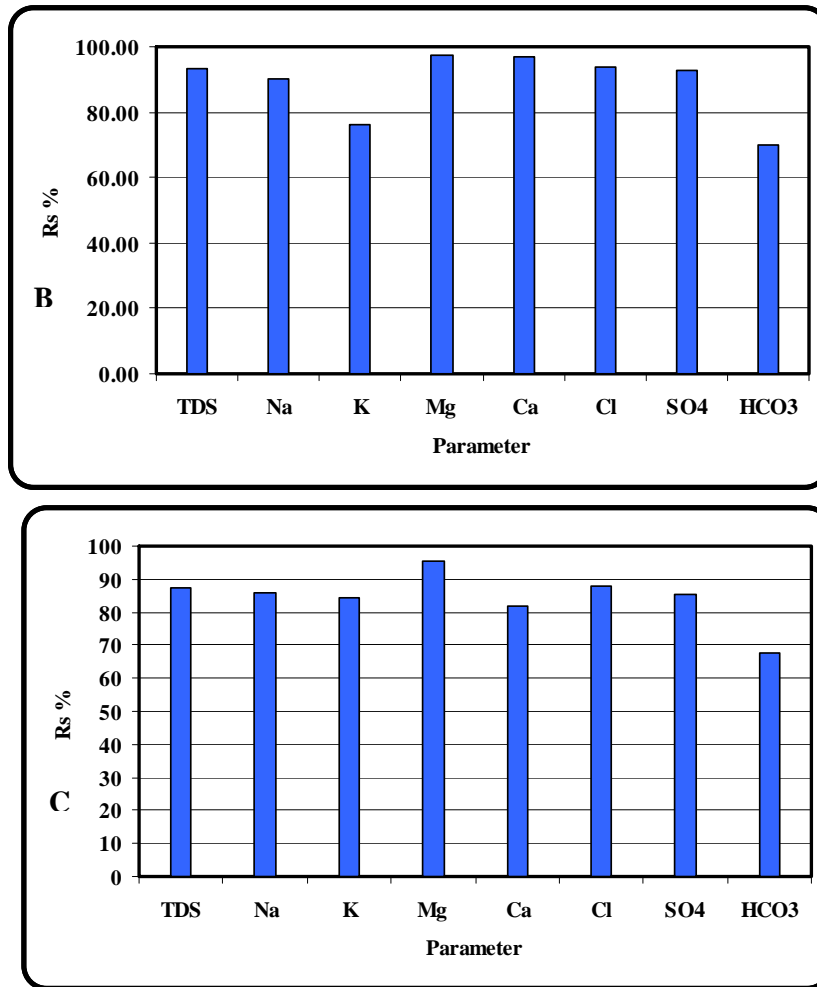


Fig. 5: Rejection of TFC membrane to the different ions present in A) brackish, B) saline and C) Sea water samples.

Rejection of hypothetical salts:

The desalting degree of a membrane is commonly reported as the percent rejection of electrolytes (hypothetical salts in natural water, NaCl, MgCl₂, CaCl₂, MgSO₄, CaSO₄ and Ca (HCO₃)₂). The desalting degree can be considered a useful parameter in estimating the rejection of some compounds. Table (4) shows the feed, rejected, permeated and desalting degree of hypothetical salts during desalination processes of different samples. Computation of the rejected ions as percent of TDS reveals that the salts of post treatment do not change after the desalination process, but the changes are related to its rejection percent (TDS of the pre- and post-treatment).

From the table, it is obvious that the rejection percent increases with feed salinity increases from brackish to saline water but decreases for sea water. This is also due to difference of applied pressure in each case, where it is 20, 35 and 40 bars for three samples, respectively. Other factors, such as concentrations of different salts in water play an important role in rejection mechanism of the membrane. For example, increasing the concentration of divalent salts of MgCl₂ and CaSO₄ from 868.33 and 494.79 mg/l in brackish water to 1918.02, 1263.98 mg/l in saline water, respectively, increased the salt rejection percent. In other words, when MgCl₂ and CaSO₄ salts concentration increases in feed water, the rejection percent increases, this is because of the increase their concentration involves the formation of a screen beside scaling effect of CaSO₄ salt. Also, when NaCl salts concentration increased from 1279.31 mg/l in feed brackish water to 3685.64 mg/l in feed saline water, the rejection percent increases, where the increase of Ca²⁺ concentration in feed saline water sample than feed brackish water generally increased Cl⁻ rejection i.e., chloride ions retention is higher when the quantity of divalent cations is dominating (Paugam *et al.*, 2003).

Table 4: Comparing of the different hypothetical salts in the feed, rejected, permeated and desalting degree (Rs %) for brackish, saline and sea water samples.

Sample	TDS Before	TDS After	Salts	Na Cl	Mg Cl ₂	Mg SO ₄	Ca Cl ₂	Ca SO ₄	Ca (HCO ₃) ₂
Brackish	2971.68	362.10	Feed	1279.31	868.33	84.10	--	494.79	245.16
			Rejected	1009.40	861.45	44.85	--	472.81	221.08
			Permeate	269.91	6.88	39.25	--	21.98	24.08
			Rs %	78.90	99.21	53.33	--	95.56	90.18
Saline	9062.53	568.97	Feed	3685.64	1918.02	--	2135.73	1263.98	59.16
			Rejected	3284.31	1862.09	--	2102.25	1188.82	56.09
			Permeate	401.33	55.92	--	33.48	75.15	3.08
			Rs %	89.11	97.08	--	98.43	94.05	94.80
Sea	44703.58	5730.71	Feed	34524.58	5793.58	3209.72	--	894.07	281.63
			Rejected	29454.62	5647.45	2805.13	--	796.65	269.03
			permeate	5069.95	146.13	404.59	--	97.42	12.61
			Rs %	85.31	97.48	87.39	--	89.10	95.52

Rejection sequence of hypothetical salts:

Figures (6 & 7) show the concentration of the different salts of NaCl, MgCl₂, CaCl₂, MgSO₄, CaSO₄ and Ca (HCO₃)₂ before and after desalination processes of different samples and their rejection sequence. Each water sample either before or after desalination contains at least five hypothetical salts that could be written as follows:

- In Brackish groundwater:

$$R_s \text{ MgCl}_2 > R_s \text{ CaSO}_4 > R_s \text{ Ca (HCO}_3)_2 > R_s \text{ NaCl} > R_s \text{ MgSO}_4$$

- In Saline groundwater:

$$R_s \text{ CaCl}_2 > R_s \text{ MgCl}_2 > R_s \text{ CaSO}_4 > R_s \text{ NaCl} > R_s \text{ Ca (HCO}_3)_2$$

- In Sea water:

$$R_s \text{ Ca (HCO}_3)_2 > R_s \text{ MgCl}_2 > R_s \text{ CaSO}_4 > R_s \text{ MgSO}_4 > R_s \text{ NaCl}$$

The rejection behavior can be illustrated as follows;

Rejection of chloride salts (MgCl₂, CaCl₂ and NaCl):

The high rejection of MgCl₂ and CaCl₂ salts relative to NaCl salt is due to two factors; the first one is the diffusivity (diffusion coefficient) of salts, where NaCl salt has diffusivity of $1.48 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ more than that of MgCl₂ and CaCl₂, 1.04 and $1.11 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$, respectively (Schaepe *et al.*, 2001). So, NaCl salt is more permeable through the membrane than MgCl₂ and CaCl₂ salts. The second factor based on the charge of the membrane, where the presence of magnesium and calcium ions could alter the sign of the membrane from negative to positive charge, so that the membrane surface becomes positively charged. This could explain the fact that those salts are more rejected than NaCl, where Mg²⁺ and Ca²⁺ are the co-ions (ion with the same sign of the charge as the membrane charge) in case of MgCl₂ and CaCl₂ and have a higher valence than chloride which is the co-ion in the case of NaCl. On the basis of Donnan exclusion theory, a high co-ion valence causes a higher salt rejection (Schaepe *et al.*, 2001).

Rejection of sulphate and bicarbonate salts (CaSO₄, MgSO₄ and Ca (HCO₃)₂):

In brackish water sample, which contains three salts, the sequence rejection is CaSO₄ > Ca (HCO₃)₂ > MgSO₄, i.e., calcium salts are more rejected than magnesium salt. The membrane appeared to be positively charged in the presence of the three salts. The more rejection of CaSO₄ than Ca (HCO₃)₂ in brackish and saline groundwater samples is due to that the membrane is negatively charged, so the co-ions SO₄²⁻ (high valence) are highly rejected compared to HCO₃⁻ (Ahmad *et al.*, 2003). In sea water sample, it is obvious that Ca (HCO₃)₂ is more rejected than CaSO₄, this may be due to the low concentration of calcium bicarbonate in feed solution (281.63 mg/l).

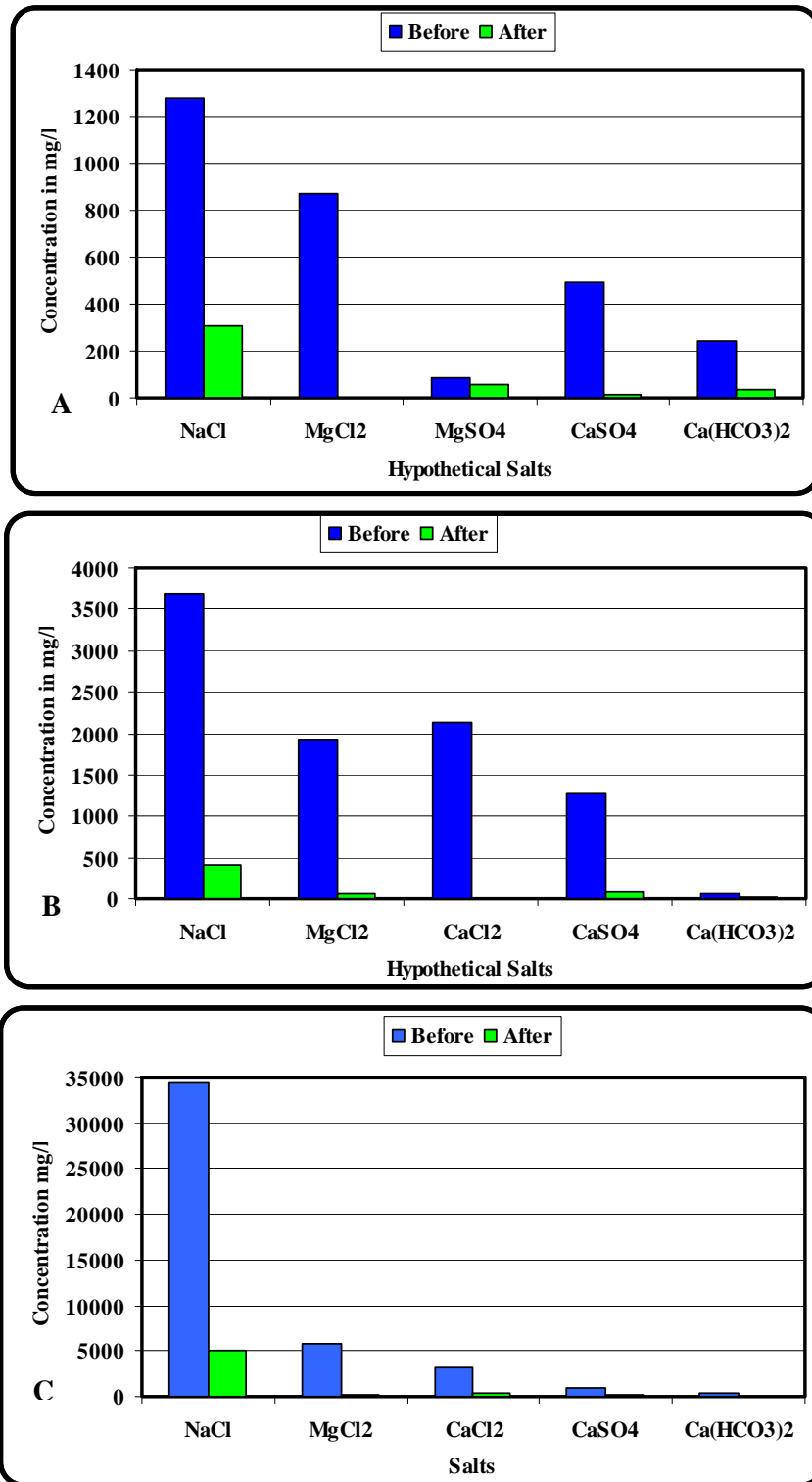


Fig. 6: Concentration of different hypothetical salts before and after desalination process for A) brackish, B) saline and C) Sea water samples.

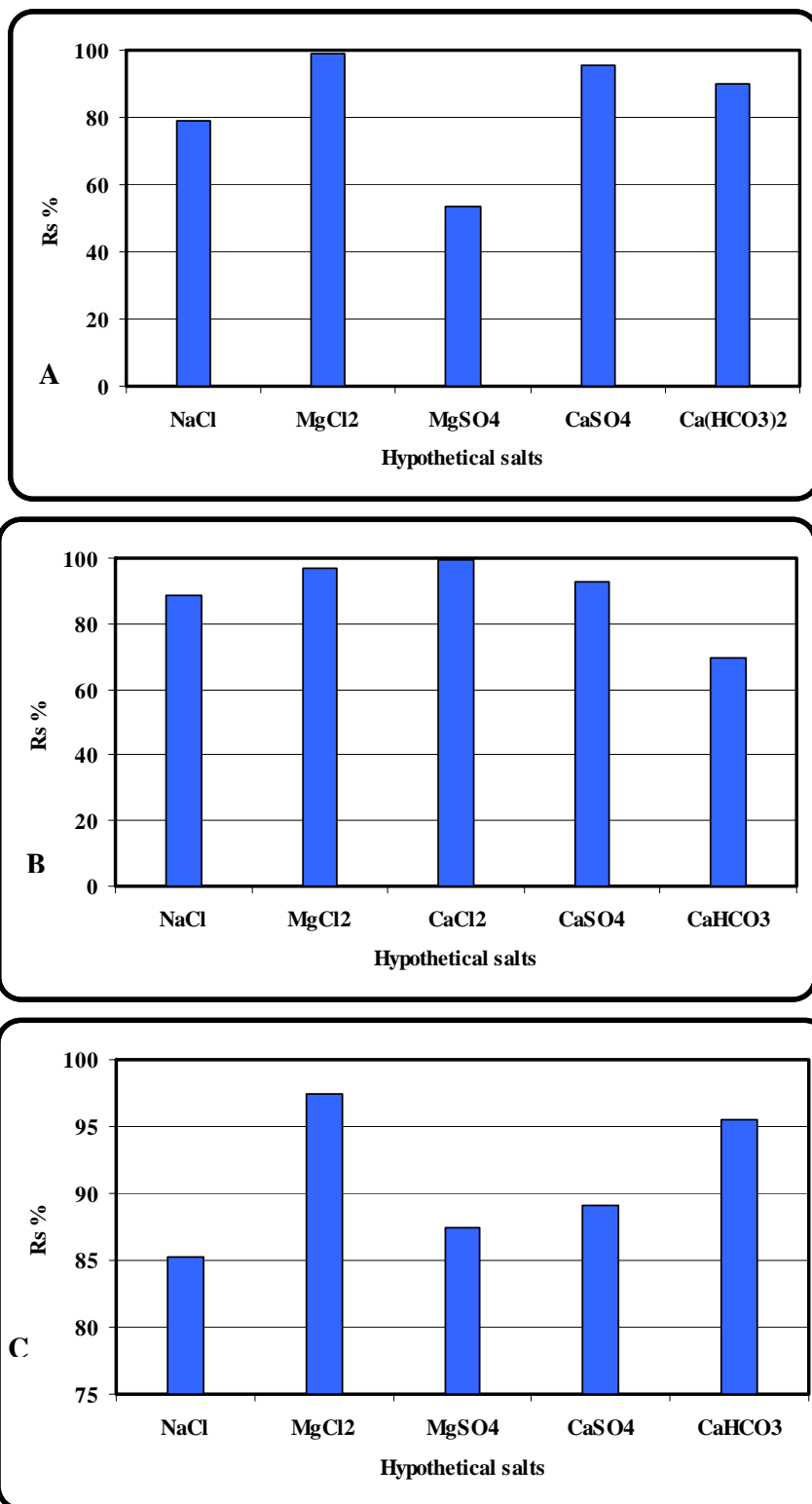


Fig. 7: Rejection of TFC membrane to the different salts present in A) brackish, B) saline and C) Sea water samples.

Removal of boron and strontium:

The concentrations of high significant metals, boron and strontium, before and after desalination process are shown in Table (5). Despite high rejection ($\geq 87\%$) of ionic species from brackish, saline seawater, the removal of boron by RO has proven challenging due to symmetric structure of boric acid which is uncharged and has trigonal structure in addition to its small size. Therefore, boric acid is nonpolar, which causes it to interact very differently with membrane materials relative to charged salt ions and polar water molecules (Jaehong Kim *et al.*, 2009). However, boron removal increases as applied pressure and feed salinity increase. On the other hand, the prepared membranes have high rejection percent for strontium because it similar to Ca^{2+} and Mg^{2+} metals.

Table 5: The concentration of boron and strontium before and after desalination process and their rejection percent using TFC membranes.

Sample	Brackish			Saline			Sea water		
	Before	After	Rejection %	Before	After	Rejection %	Before	After	Rejection %
B ⁺⁺⁺	1.66	0.304	81.68	3.94	1.21	69.28	5.258	1.2	77.17
Sr ⁺⁺	4.057	0.272	93.29	16.66	0.558	96.65	8.626	1.07	87.59

Evaluation of desalinated water for drinking:

The desalination process of the three samples show that the desalted water produced from one stage of desalination of brackish and saline groundwater samples is acceptable for drinking according to WHO and Egyptian guidelines, Table (6). On the other hand, when our TFC membranes are used in sea water desalination, they must be operated in two stages, where the produced water from the first process is pressurized again on other membrane. So, we can say that the membranes prepared at our labs are more preferable for brackish water desalination.

Table 6: Chemical analysis of brackish, saline groundwater and sea water samples compared with water quality guidelines for human drinking.

Parameter	Brackish		Saline		Sea water		Egyptian standards	WHO
	Before	After	Before	After	Before	After		
TDS	2971.6	362.1	9062.5	591.79	44703.5	5730.7	1200	1000
PH	7.18	8.08	6.99	7.88	8.13	7.81	--	6.5 – 9.2
Sodium	525	98.77	1466.6	144	14000	1998.4	--	200
Potassium	14	7.62	100	23.89	350	55		
Calcium	268.8	11.52	1248	38.4	422.4	76.8	200	--
Magnesium	209.9	11.66	419.9	11.66	1959.5	93.31	150	--
Sulfates	488	50	1050	75	3375	494	250 – 400	400
Chloride	1335	166.87	4746.6	289.25	24475	2981.5	500	250
Boron	1.66	0.304	3.94	1.21	5.258	1.2	--	0.5 – 1
Strontium	4.057	0.272	16.66	0.558	8.626	1.07	--	4

All concentrations in mg/l.

Conclusion:

TFC membrane is acceptable for practical uses in desalination of brackish, saline and sea water, where their salt rejection (%) was 87.8, 93.7 and 87.18, respectively. In other words, the water salinity of brackish (2971.6 mg/l), saline groundwater (9062.5 mg/l) and sea water (44703.5 mg/l) became 362.1, 591.79 and 5730.7 mg/l after desalination process in one run of such membrane and produced water salinity can be decreased by increasing the number of the used membranes. Therefore, after treatment of brackish and saline groundwater samples, the treated water has a low value of TDS which is accepted by International standards as their salinity is suitable for human consumption of drinking water. On the other hand, the water flux (J_w) increases from 27.77 L/m².h for brackish water to 94.44 L/m².h for saline water with increasing applied pressure increases from 20 to 35 bar. The decreases of J_w of sea water sample 33.33 L/m².h is due to the slight difference between the applied pressure on this extremely saline water and natural osmotic pressure and high concentration of salts accumulated on the membrane surface that restricts the water permeability through the membrane.

References

- Ahmad, L., B.S. Ooi and J.P. Choudhury, 2003. "Preparation and characterization of co-polyamide thin film composite membrane from piperazine and 3, 5-diaminobenzoic acid". *Desalination*, 158: 101-108.
- Al-Sofi, M., 2001. Seawater desalination — SWCC experience and vision. *Desalination*, 135: 121-139.
- American Society for Testing and Materials [ASTM], 2002. "Water and environmental technology ". Annual book of ASTM standards, U.S.A. Sect., 11(11.01), and 11.02, West Conshohocken.
- Cadotte, J.E., 1981. "Interfacially synthesized reverse osmosis membrane". US Patent 4: 277,344.

- Cadotte, J.E., R.J. Petersen, R.E. Larson and E.E. Erickson, 1980. "New thin-film composite seawater reverse-osmosis membrane". *Desalination*, 32: 25-31.
- Childress, E. and M. Elimelech, 2000. "Relating nanofiltration membrane performance to membrane charge (Electrokinetic) characteristics". *Environmental Science and technology*, 34: 3710-3716.
- Huan, G., W. Wang and Q. Du, 2009. "Preparation and Characterization of a Novel Nanofiltration Membrane". *Fibers and Polymers*, 10(6): 797-801.
- Jaehong Kim, Hoon Hyung, Mark Wilf, Jong-Sang Park and B. Jess Brown, 2009. "Boron Rejection by Reverse Osmosis Membranes: National Reconnaissance and Mechanism Study boron Rejection by Reverse". *Desalination and water purification research and development program report.*, 127: 20.
- Kosutic, K., D. Dolar and B. Kunst, 2006. "On experimental parameters characterizing the reverse osmosis and nanofiltration membranes active layer". *J. Membr. Sci.*, 282: 109-114.
- Mattaraj, S., C. Jarusutthirak, C. Charoensuk and R. Jiratananon, 2011. "A combined pore blockage, osmotic pressure, and cake filtration model for cross flow nanofiltration of natural organic matter and inorganic salts" *Desalination*, 274: 182-191.
- Paugam, L., S. Taha, G. Dorange, P. Jaouen and F. Quéméneur, 2003. "Mechanism of nitrate ions transfer in nanofiltration depending on pressure, pH, concentration and medium composition". *Journal of Membrane Science*, 231: 37-46.
- Petersen, R.J., 1993. "Composite reverse osmosis and nanofiltration membranes". *J. Membr. Sic.*, 83(1): 81-150.
- Sanchuan, Y., L. Meihong, L. Xuesong, and G. Congjie, 2009. "Performance enhancement in interfacially synthesized thin-film composite polyamide-urethane reverse osmosis membrane for seawater desalination". *J. Membr. Sci.*, 342: 313-320.
- Schaep, J., B. Van der Bruggen, C. Vandecasteele and D. Wilms, 1998. "Influence of ion size and charge in nanofiltration". *Separation and Purification Technology*, 14(1-3): 155-162.
- Schaep, J., C. Vandecasteele, A.W. Mohammad and W.R. Bowen, 2001. "Modeling the retention of ionic components for different nanofiltration membranes". *Separation and Purification Technology*, 22-23: 169-179.
- Schaep, J., C. Vandecasteele, B. Peeters, J. Luyten, C. Dotremont and D. Roels, 1999. "Characteristics and retention properties of a mesoporous Al₂O₃ membrane for nanofiltration, *J. Membr. Sci.*, 163: 229-237.
- Teixeira, M.R., J.R. Maria and N. Marianne, 2005. "The role of membrane charge on nanofiltration performance". *J. Membr. Sci.*, 265: 160-166.
- United Nation, 2009. "Statistics: Graphs and Maps, [Online] Available at <http://www.unwater.org/statistics.html> (accessed 6 November), WWW Article.
- Van Gestel, T., C. Vandecasteele, A. Buekenhoudt, C. Dotremont, J. Luyten, R. Leysen, B. Van der Bruggen, and G. Maes, 2002. "Salt retention in nanofiltration with multilayer ceramic TiO₂ membranes". *J. Membr. Sci.*, 209: 379-389.
- Walha, K., R.B. Amar, L. Firdaous, F. Quéméneur and P. Jaouen, 2007. "Brackish groundwater treatment by nanofiltration, reverse osmosis and electrodialysis in Tunisia: performance and cost comparison". *Desalination*, 207: 95-106.