Journal of Materials and Environmental Sciences
ISSN : 2028-2508

JMES, 2017 Volume 8, Issue 6, Page 2006-2012

http://www.jmaterenvironsci.com /

Determination of the Treatment Efficiency of Different Commercial Membrane Modules for the Treatment of Groundwater

Hisham A. Maddah[1,2], Abdulazez S. Alzhrani[1], Ahmed M. Almalki[1], M. Bassyouni[1,3], M. H. Abdel-Aziz[1,4], Mohamed Zoromba[1,5], Mohammed A. Shihon[6]

[1]Department of Chemical Engineering, King Abdulaziz University, Rabigh, Saudi Arabia
[2]Department of Chemical Engineering, University of Southern California, Los Angeles, United States
[3]Department of Chemical Engineering, Higher Technological Institute, Tenth of Ramadan City, Egypt
[4]Chemical Engineering Department, Alexandria University, Alexandria, Egypt
[5]Department of Chemistry, Faculty of Science, Port Said University, Port Said, Egypt
[6]Department of Chemical Engineering, King Abdulaziz University, Jeddah, Saudi Arabia

Received 18 Jan 2017,
Revised 13 Mar 2017,
Accepted 19 Mar 2017

Keywords

- ✓ Groundwater;
- ✓ Membrane;
- ✓ Filtration;
- ✓ Salinity;
- ✓ Desalination;
- ✓ TDS;
- ✓ Water Treatment

hmaddah@kau.edu.sa ,
Phone: (+1) 5203697386

Abstract

The goal of this study was to identify the treatment efficiency of various membrane modules in the treatment of Yanbu Groundwater. The membrane treatment efficiency was calculated from the removal percentages of groundwater conductivities, associated with TDS, of the groundwater at Yanbu city. The experiment work involved four commercial membranes and they were Polyvinylidene difluoride (FP100), Polyethersulphone (ES404), Polyamide low-pressure film (AFC40) and Polyamide high-pressure film (AFC99). Different pressure values were applied on each membrane type to see the effect of the pressure on the treatment efficiency and thereby selecting the optimal operating pressure for the treatment of the groundwater. The ideal membrane for the treatment was selected based on a comparison between the four membranes. The optimal operating pressures for the first three membranes FP100, ES404 and AFC40 were 10, 30 and 60, respectively. However, the optimal operating pressure for AFC99 membrane was 61.8 bar which was not similar to the maximum operating pressure reported in the manuals that was 64 bar. Results showed that applying higher pressures would increase the treatment efficiency except for the last membrane type AFC99. It was found that the best membrane module for the treatment of the groundwater at Yanbu city would be AFC40 with a potential to reduce fouling (prefiltration) in advanced water treatment plants with 7% treatment efficiency.

1. Introduction

The increase and diversities in today's water uses lead to have high environmental impacts on groundwater and surface water. There is a growing demand to improve current water treatment technologies for different impurities from various water resources [1-3]. Industrial water contains heavy metals, toxic organics such as phenol compounds and other dissolved solids that may contaminate groundwater reservoirs if not treated beforehand [4]. Heavy metals and dissolved solids are considered as important indicators to evaluate water quality particularly in fresh water streams such as seawater, rivers and groundwater. The presence of either heavy metals or dissolved solids in fresh water is an indication that we have diverse water contaminants [5-7].

Membranes can separate contaminants from groundwater by passing clean water through tubular polymer films while preventing impurities on the other side. Membrane filtrations are utilized in desalination applications for the production of potable water because of their lower capital costs compared to other industrial treatment processes [8]. There are four categories for membrane processes which include pressure-driven, solute-transfer, thermal and hybrid processes as shown in Table 1 [9]. Since a membrane is a thin layer of semi-permeable material, it can separate substances by applying a driving force across the membrane. The aim of membrane filtration processes is to reject pollutants such as salt, microorganisms, particulates, and organics from water [10].

There are four membrane filtration types which include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). MF membranes separate large suspended or colloidal particles from dissolved solids at moderate pressure. UF membranes are able to eliminate medium to high molecular weight components. However, NF membranes are designed for specific separations of low molecular weight compounds. NF membranes require more energy due to the application of higher pressures than MF or UF because of the small pores size. The most advanced membranes are RO membranes that are operated at high operating pressures with an effective removal of nearly all inorganic pollutants from water. [10-16]. Table 2 shows common applications and ideal separation processes of the different membrane types [14]. The range of nominal membrane pore sizes for the different membranes is shown in Table 3 and Figure 1 [10-16]. It can be found that as the pore size decreases, the operating pressure increases; and this is due to having less free volume for water to go through.

There are numerous materials for the construction of MF and UF membranes including the following: cellulose acetate, polyvinylidene fluoride, polyacrylonitrile, polypropylene, polysulfone, polyethersulfone, or other polymers. Each membrane has its own characteristics and properties which vary based on the used material [10].

Table 1: Various membrane processes for water treatment [9]

Membrane process	Mechanism for Contaminants Removal	Examples
Pressure-driven	Pore size	MF, UF, NF, RO
Solute-transfer	Electrochemistry or diffusion	ED, D*
Thermal	Phase change	MD, PV*
Hybrid	Pretreatment, adsorption, ion exchange or coagulation	-

*ED: Electrodialysis; D: Water diffusivity; MD: Membrane distillation; PV: Photovoltaic

Table 2: Various membrane separation processes and their applications [9]

Membrane Type	Ideal Separation Processes	Common Applications
Microfiltration (MF)	Pretreatment	Filtration
Ultrafiltration (UF)	Proteins, carbohydrates and enzymes	Whey protein concentration
Nanofiltration (NF)	Minerals and salts	Desalination
Reverse Osmosis (RO)	Clean-up of waste effluents	Purification of process water

Table 3: Typical pore size and operating pressure of various membrane types [11-16]

Membrane Type	Pore Size (microns)	Operating Pressure (bar)
Microfiltration (MF)	0.1-10 (1-1000 nm)	1-6.2
Ultrafiltration (UF)	0.01-0.1 (1-100 nm)	1-10
Nanofiltration (NF)	< 0.001 (< 1 nm)	20-40
Reverse Osmosis (RO)	< 0.001 (< 1 nm)	30-100

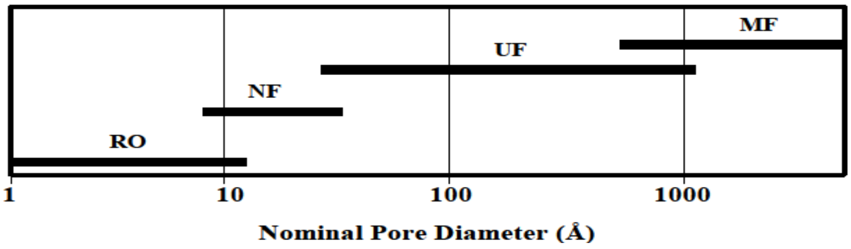

Figure 1: Typical pore diameter of different membranes [17]

However, cellulose acetate or ployamide materials are utilized to design NF and RO membranes. Cellulose membranes are operated within a narrow pH range of 4 to 8 to avoid membrane biodegradation [10]. There are wide range of membrane system configurations which includes a number of both polymeric and inorganic membranes. The polymeric membrane types are spiral, tubular and hollow fiber membrane while the inorganic membrane types involve ceramic and stainless steel membrane. The advantages and the ideal applications of each membrane configuration are described and listed in Table 4 [14].

Table 4: Major advantages and ideal applications of various membrane system configurations [14]

Membrane Configuration	Advantages	Ideal Applications
Spiral (Polymeric)	Cost-effective	High volume applications with no suspended solids
Tubular (Polymeric)	Highly resistant to plugging	Large amounts of suspended solids or fibrous compounds
Hollow fiber (Polymeric)	Possibility of backwashing	Low solids liquid streams
Ceramic (Inorganic)	function at extreme pH and temperature conditions	Value added applications such as fractionation of proteins in milk
Stainless Steel (Inorganic)	Work at elevated particulate solids or viscosity	Demanding applications with aggressive process conditions or feed streams

2. Methodology and Experiment

Water samples from the ground water at Yanbu city are taken with a concentration of 35.7 milli-Siemens (mS). Four commercial membranes, as shown in Table 5, have been utilized to determine the ideal membrane type for the treatment. Different pressure values are applied on the four membranes as tabulated in Table 6 to find out the optimal operating pressure for the treatment. Figure 2 shows the membrane filtration test unit (Model: TR 14) that was used in the experiments. The exact technique for performing the experiment work is elucidated from the procedure and desired operating conditions of each membrane type in Table 7 as well as the membrane filtration test unit process flow diagram in Figure 3 [18, 19].

Table 5: Characteristics and information for the four commercial membrane types [18-22]

#	Type of Membrane	Material	Max. pH Range	Max. Pressure (bar)	Applicable Module
1	FP100	Polyvinylidene difluoride (PVDF)	1.5-12	10	UF
2	ES404	Polyethersulphone	1.5-12	30	NF
3	AFC40	Polyamide low-pressure film	1.5-9.5	60	RO
4	AFC99	Polyamide high-pressure Film	1.5-12	64	RO

Table 6: Different applied pressure values for the four commercial membrane types

#	Type of Membrane	Applied Pressure Values (bar)			
		P1	P2	P3	P4
1	FP100	4	6	8	10
2	ES404	10	20	25	30
3	AFC40	30	40	50	60
4	AFC99	61	62	63	64

Table 7: Procedure and desired operating conditions for the four commercial membrane types [18-22]

#	Type of Membrane	Open Valves	Sampling Valves	Retentate Control Valve	Membrane Maximum Inlet Pressure (bar)
1	FP100	V2, V6, V7, V11 and V15	Sampling 1	V15	10
2	ES404	V2, V6, V8, V12 and V16	Sampling 2	V16	30
3	AFC40	V2, V6, V9, V13 and V17	Sampling 3	V17	60
4	AFC99	V2, V6, V10, V14 and V18	Sampling 4	V18	64

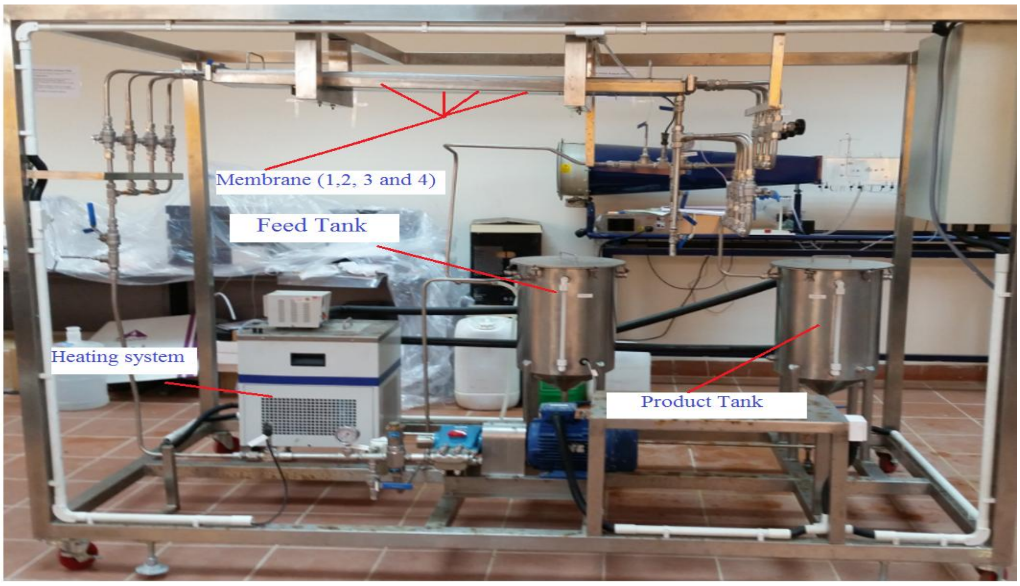

Figure 2: The membrane filtration test unit; Model: TR 14

In each experiment, the feed tank (Tank 1) was filled up alternatingly with 15 liters of Yanbu Groundwater. The water fed at room temperature (25°C) and the level of water was fixed with a level controller. Temperature transmitters, pressure indicators and flow transmitters were used to ensure the system operating conditions. Open and closed valves of the membrane filtration test unit are demonstrated in Table 7. The pump was operated to apply different pressure set points on each membrane, as shown in Table 6. A pressure gauge was used to control the pressure increase. The system was operated for a short time (1-4 minutes) to take the required samples in order to determine the conductivity. Results of the four membranes were compared for the determination of the ideal membrane for the treatment.

Equation (1) is used to calculate the exact removal percentage (treatment efficiency) of each membrane from the initial and final samples concentrations [20].

$$\mathbb{R} = \frac{C_i - C_o}{C_i} \times 100 \tag{1}$$

Where; $\mathbb{R}$ = Groundwater membrane removal percentage, %
C_i = Groundwater inlet conductivity, feed, mS
C_o = Groundwater outlet conductivity, product, mS

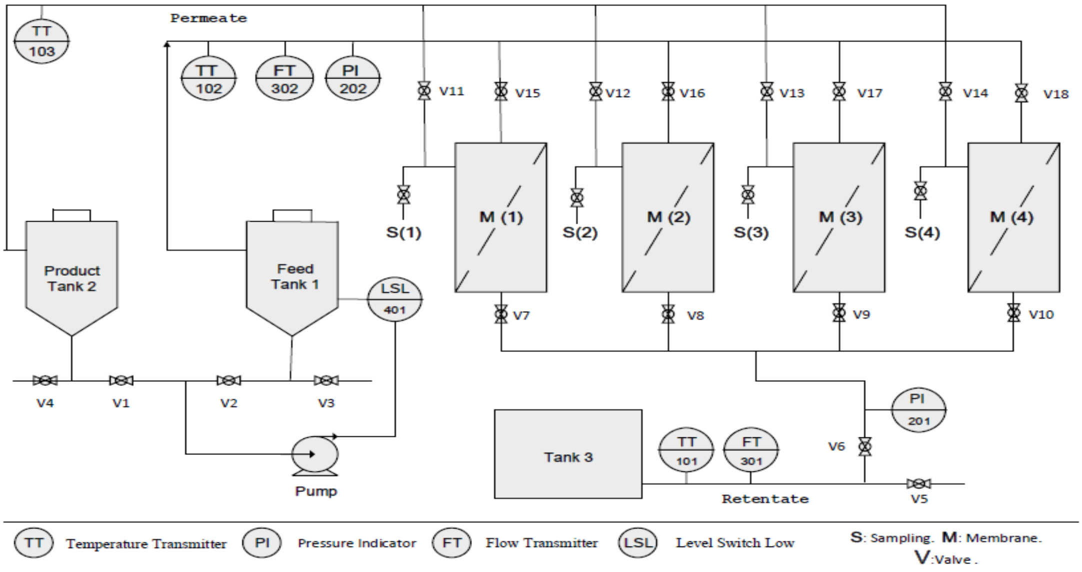

Figure 3: Process flow diagram of the membrane filtration test unit; Model: TR 14; reported numbers below TT, PI, FT and LSL are just the serial number of that unit [18, 19]

3. Results and Discussion

Results showed that the optimal operating pressures for the three membranes FP100, ES404 and AFC40 were similar to the maximum operating pressures which were 10, 30, 60 bar, respectively. However, the optimal operating pressure for AFC99 membrane was 61.8 bar which was not the similar to the maximum operating pressure that was 64 bar. It was found that AFC40 would be the optimal membrane choice among the other commercial membranes for the treatment of Yanbu Groundwater with a treatment efficiency of 7%.

Figures 4 to 7 show the effect of the applied pressure of the various commercial membranes FP100, ES404, AFC40 and AFC99 on the groundwater conductivity (TDS concentration) at Yanbu. In Figure 4, it can be found that when the applied pressure increased on the FP100 membrane, the conductivity increased and then decreased sharply; this could be associated with the accumulated impurities on the membrane surface from the first sample that were washed out with the second sample and could not be removed unless there was a high pressure applied. ES404 membrane in Figure 5 shows fluctuation in the conductivity where the peak conductivity value was determined to be at the beginning as expected because of the low applied pressure which might drive more impurities with the passing water. An increase in the conductivity occurred with the third sample due to particles accumulation on the membrane surface.

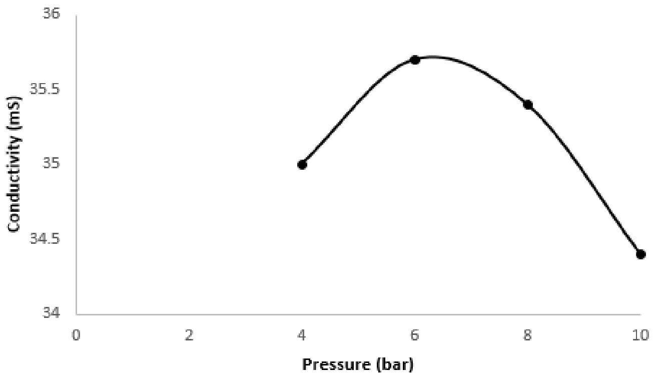

Figure 4: Effect of different applied pressures on the treatment of the Yanbu Groundwater in membrane #1 (FP100)

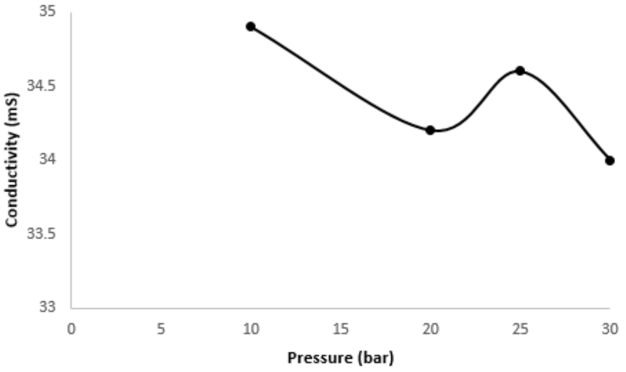

Figure 5: Effect of different applied pressures on the treatment of the Yanbu Groundwater in membrane #2 (ES404)

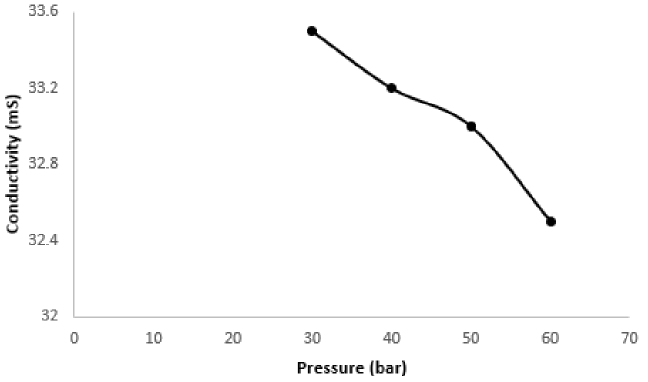

Figure 6: Effect of different applied pressures on the treatment of the Yanbu Groundwater in membrane #3 (AFC40)

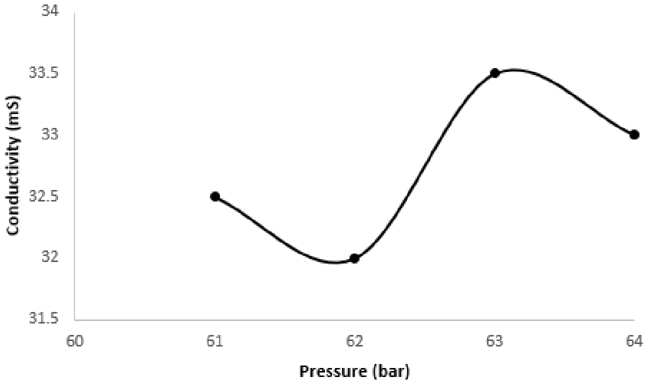

Figure 7: Effect of different applied pressures on the treatment of the Yanbu Groundwater in membrane #4 (AFC99)

The ideal and optimum results were reserved for the AFC40 membrane in Figure 6 where we had a smooth and linear decrease in the conductivity as we increased the applied pressure since water was forced to go through pores faster leaving more contaminants behind. Particles accumulation observation was the reason of the fluctuation in water conductivity in the AFC99 membrane as shown in Figure 7. The overall treatment efficiency of the four commercial membranes for Yanbu Groundwater is shown in Figure 8. The treatment efficiency of AFC40 membrane was around 7% which may reduce fouling potential and enhance diffusion [23, 24]. The experimental analysis concluded that there is an inverse correlation between the applied pressure and the water conductivity.

Conductivities of the final water product for each of the four commercial membranes has been measured and reported in Table 8. To simplify our calculations, the applied pressure that is related to the previous conductivity results was determined by taking the average pressure values. A more accurate results has been found for the relation between water conductivity and the applied pressure on the membrane from the overall study. Obviously, we have the same previous results in which high-pressure values reduce TDS or water conductivity of the groundwater at Yanbu.

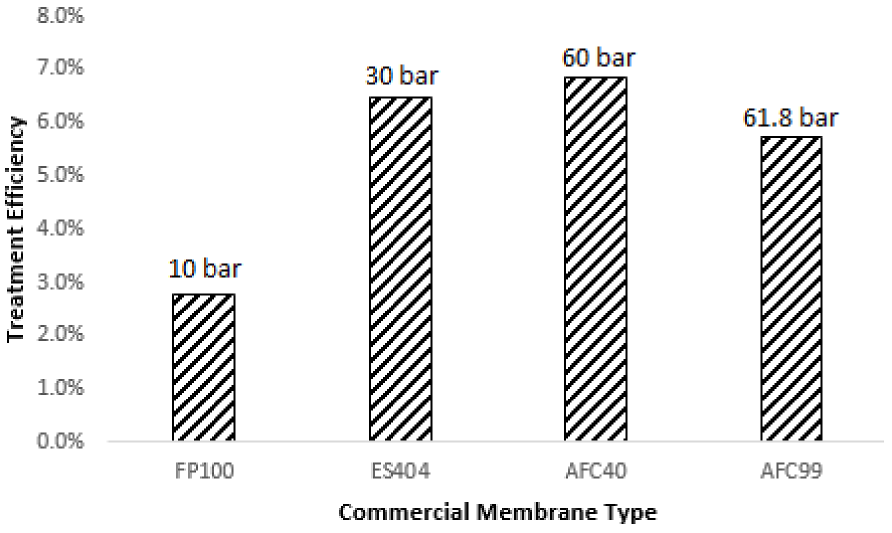

Figure 8: The overall treatment efficiency of the four commercial membranes for Yanbu Groundwater

Table 8: Characteristics of the water product for the four commercial membranes at their averaged pressures

#	Type of Membrane	Average Pressure (bar)	Sample Concentration (mS)
1	FP100	7	34.2
2	ES404	21.25	32.2
3	AFC40	45	32
4	AFC99	62.5	32.6

Conclusions

The four commercial membranes (FP100, ES404, AFC40 and AFC99) have been investigated in terms of their treatment efficiency of the groundwater at Yanbu under different applied pressures. The groundwater feed samples had a conductivity of 35.7 mS. The aim of this study was to determine the ideal membrane type for the treatment of Yanbu Groundwater among the four commercial membranes.

Results showed that the optimal operating pressures for the three membranes FP100, ES404, AFC40 were 10, 30, 60 bar, respectively. However, the optimal operating pressure for AFC99 membrane was 61.8 bar. It is proposed that higher pressure values would increase the removal efficiency due to the reduction in conductivity.

Our findings recommend that AFC40 is the optimum membrane choice among the other membranes for the treatment of Yanbu Groundwater. The treatment efficiency of AFC40 membrane was approximately 7% which may play a key role in reducing fouling issues in advance water treatment units. However, the calculated overall treatment efficiency for the final groundwater product of the other commercial membranes FP100, ES404, AFC99 were 2.8%, 6.5% and 5.7%, respectively.

References

1. Gutub S. A., Bassyouni M., Abdel-hamid S. M. S., *Life Sci. J.* 10 (2013) 464.
2. Abdel-Aziz M. H., Gutub S., Soliman M. F., Bassyouni M., *Rocznik Ochrona Środowiska* 18 (2016) 28.
3. Abdel-Aziz M. H., Bassyouni M., Soliman M. F., Gutub S., Magram S.F., *J. Mat. Environ. Sci*. 8 (2017) 1737.
4. Maddah H. A., *ARPN J. of Eng. Applied Sci.* 11 (2016) 1799.
5. Abdel-Aziz M. H., El-Ashtoukhy E-S. Z., Bassyouni M., *Metall. and Mat. Trans. B*, 47 (2016) 657.
6. Zoromba M. Sh., Ismail M.I.M., Bassyouni M., Abdel-Aziz M. H., Salah N., Memic A., Alshehry A., *Coll. Surf. A: Physicochem. Eng. Aspects* 520 (2017) 121.
7. Abdel-Aziz M. H., Bassyouni M., Mansour I. A. S., Nagi A., *J. Ind. Eng. Chem*. 20 (2014) 2650.
8. Brief T., *Tech Brief Twelve* (1999).
9. Fane A. G., *Desalination* 106 (1996) 1.
10. Filtration M., *National Drinking Water ClearingHouse* (1999).
11. Wagner J., *Osmonics. Inc.* (2001).
12. EPA N., *EPA 815-R-06-009, Office of Water* (2005).
13. Maddah H. A., Chogle A. M., *Membrane Water Treatment* 6 (2015) 477.
14. GEA Process Engineering Inc., *Membrane Filtration* (2012).
15. Emis: energie- en milieu-informatiesysteem voor het Vlaamse Gewest, *Microfiltration* (2010).
16. Smart Membrane Solutions, *Membrane Classifications* (2002).
17. Sagle A., Freeman B., *Biennial Report on Seawater Desal.* 2 (2004) 137.
18. SOLTEQ Company, *Exp. Manual Membrane Test Unit TR14* (2008).
19. ITT PCI Membranes Ltd., *TP78_25 Membranes and Modules* (2011).
20. Perry R. H., Green, D. W., *Perry's Chemical Eng. Handbook: McGraw-Hill* (1999).
21. McCabe W. L., Smith J. C., Harriott P., *McGraw-Hill* 5 (1993) 154.
22. Geankoplis C., *Prentice Hall Press* (2003).
23. Maddah H., Chogle A., *Applied Water Science* (2016) 1.
24. Maddah H. A., *Journal of Material Science and Chemical Engineering 4* (2016) 20.

(2017) ; http://www.jmaterenvironsci.com