Desalination and Water Treatment
www.deswater.com
9 (2009) 189–194

Optimum design of an RO membrane by using simulation techniques

N. Afrasiabi*, M. Ehteshami, R. Ardakanian

Department of Research and Development, Hampa Engineering Corporation, Tehran, Iran, KNTU University, Tehran, Iran, Sharif University of Technology, Tehran, Iran
email: nima.afrasiabi@gmail.com, ehteshami@kntu.ac.ir, ardakanian@sharif.edu

Received 15 September 2008; Accepted 8 November 2008

ABSTRACT

Increasing demand of fresh water, and limitation water resources, with respect to world economic growth brings up the importance of utilization of saline water.

At the current research the sensitivity analysis of ROSA was conducted. For this analysis, a single stage reverse osmosis is designed for well water specification in southern Tehran under following condition: Feed flow: 40 m^3/h and membrane Element: BW30–400 FR. The sensitivity analyses for all chemical element of base water were performed. As a result of sensitivity analysis shortest sensitivity gap, belongs to boron, and longest sensitivity gap, belongs to calcium.

Which reflects, under the same conditions, the least element to be eliminated ion is boron and the most eliminated ion is calcium, in fact the order of omitting is from lowest to the highest interval in following order "Boron, Ammonia, Nitrate, Potassium, Sodium, Bicarbonate, Fluoride,Chloride, Silica, Strontium, Barium, Sulfate, Magnesium, Calcium." The optimum element which could result proper membrane selection achieved.

Keywords: Water treatment; Saline water; Reverse osmosis; ROSA; Sensitivity analysis

1. Introduction

Iran is located in arid and semi-arid part of continent, and also its low-precipitation regime is followed by special distribution of time and place. Drought and low-water yield potential is a high possibility in country. In the normal water yield, some parts in the country such as South East and Central parts suffers most with lack of water supply potential.

Today, water treatment techniques for supply of drinking water and industrial use are highly important. For industrial usage without having proper water treatment most industrial parts and factories would have probable financial damages. This could follow by problems which would arise due to using inadequate water quality requirements.

During the current years most techniques which have been used for desalination of water usage is reverse osmosis (RO) technique [1:16]. The model of reverse osmosis system analysis (ROSA) is mostly common used for simulating RO systems, which is denoted in most references [17:37]. Also the results of this model are highly close to the real data performance [29]. For optimum design of water treatment using reverse osmosis technique, sensitivity analysis was conducted by ROSA model, and the results are as follows:

2. Procedure

ROSA design software is a tool used to estimate the stabilized performance of a new RO or NF system under design conditions, but it can also be used to

*Corresponding author.

Presented at the Conference on Membranes in Drinking and Industrial Water Production, 20–24 October 2008, Toulouse, France.

Table 1
Specification of feed water.

T (ºC)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	NH_4 (mg/l)	SO_4 (mg/l)	Cl (mg/l)	NO_3 (mg/l)	SiO_2 (mg/l)	Ba (mg/l)	Turbidity (N.T.U)	PH	HCO_3 (mg/l)
25	138.4	89.76	350	2	0.03	525	355	18.7	30	0.06	0.4	7.24	0

estimate the performance of an existing RO/NF system under prevailing actual conditions. This projected performance is based on the nominal performance specification for the FILMTEC element(s) used in that system.

In the current research the latest version of ROSA 6.1.5, has been used. The current model has been advantages compared to relevant models such as CAROL, TROI and IMSDesign:

- Most published references in literature [17:37].
- Optimization procedure [37:41].
- Precision and comparison to real data [29].

For sensitivity analysis of ROSA, the well water as feed water following specification in table 1 located at Southern Tehran was selected. The system is with single stage RO, permeate flow of 20 m^3/h, and four parallel pressure vessel having four elements (BW30–400 FR) in each one was design. Then sensitivity analysis for each of the constitutes ions in feed water were conducted.

For sensitivity analysis of feed ions, all constitutes of feed water were assumed have constant concentrations. Then the concentration of each ion were changed from zero to amount of changes shown in permeate water. For all process design non "Design warning" were considered for acceptance of confidence level.

In the current procedure accuracy of double digit precision for each ion would be shown proper concentration in permeate and feed water. If the ion concentration would increase further we would have reaction shown in the feed water. With the mention procedure we would have twenty points for each ion. We could find interval gaps of sensitivity analysis which is shown on Table 2.

Sensitivity analysis for each ion = $A–B$ (1)
A = ion concentration at last (nth) simulation step (mg/L)
B = ion concentration at n–1 step (mg/l)

In this step you would see reaction in the permeate water within range of 0.01 mg/l.

Table 2
Analysis gaps for the ions used in the simulation model.

Ca	Mg	SO_4	Ba	Sr	SiO_2	Cl	F	HCO_3	Na	K	NO_3	NH_4	Boron
1.71	1.65	1.47	1.43	1.42	0.86	0.59	0.51	0.06	0.18	0.08	0.04	0.05	0.01
3.4	3.28	2.95	2.85	2.83	1.71	1.17	1	0.14	0.34	0.14	0.09	0.08	0.02
3.39	3.27	2.94	2.84	2.81	1.71	1.18	1	0.18	0.34	0.15	0.14	0.08	0.02
3.38	3.26	2.94	2.83	2.78	1.71	1.17	1	0.25	0.35	0.15	0.13	0.08	0.02
3.38	3.25	2.95	2.82	2.78	1.71	1.17	1	0.29	0.34	0.14	0.14	0.08	0.02
3.37	3.25	2.95	2.82	2.78	1.71	1.17	1	0.34	0.34	0.15	0.14	0.08	0.02
3.36	3.23	2.95	2.81	2.76	1.71	1.16	1	0.38	0.34	0.15	0.13	0.08	0.01
3.36	3.22	2.95	2.8	2.75	1.71	1.17	1	0.42	0.34	0.14	0.14	0.08	0.02
3.34	3.22	2.95	2.8	2.78	1.71	1.17	1	0.45	0.34	0.15	0.14	0.07	0.02
3.35	3.2	2.96	2.78	2.69	1.71	1.16	1	0.48	0.34	0.15	0.13	0.08	0.02
3.33	3.2	2.96	2.77	2.71	1.71	1.17	1	0.51	0.34	0.14	0.14	0.08	0.02
3.33	3.19	2.96	2.77	2.71	1.71	1.16	1	0.54	0.35	0.15	0.13	0.08	0.01
3.32	3.18	2.96	2.77	2.7	1.71	1.16	1	0.57	0.33	0.14	0.14	0.08	0.02
3.31	3.17	2.97	2.39	2.68	1.71	1.17	1	0.59	0.34	0.15	0.14	0.08	0.02
3.31	3.16	2.97	3.11	2.68	1.71	1.16	1	0.61	0.34	0.15	0.13	0.08	0.02
3.3	2.57	2.96	2.75	2.66	1.71	1.16	1	0.63	0.33	0.14	0.14	0.08	0.02
3.3	2.5	2.97	2.73	2.66	1.71	1.16	1	0.65	0.34	0.15	0.14	0.08	0.02
2.99	2.48	2.98	2.73	2.64	1.71	1.16	1	0.66	0.34	0.15	0.13	0.08	0.01
3.58	2.44	2.97	2.72	2.64	1.71	1.15	1	0.69	0.78	0.14	0.14	0.08	0.02

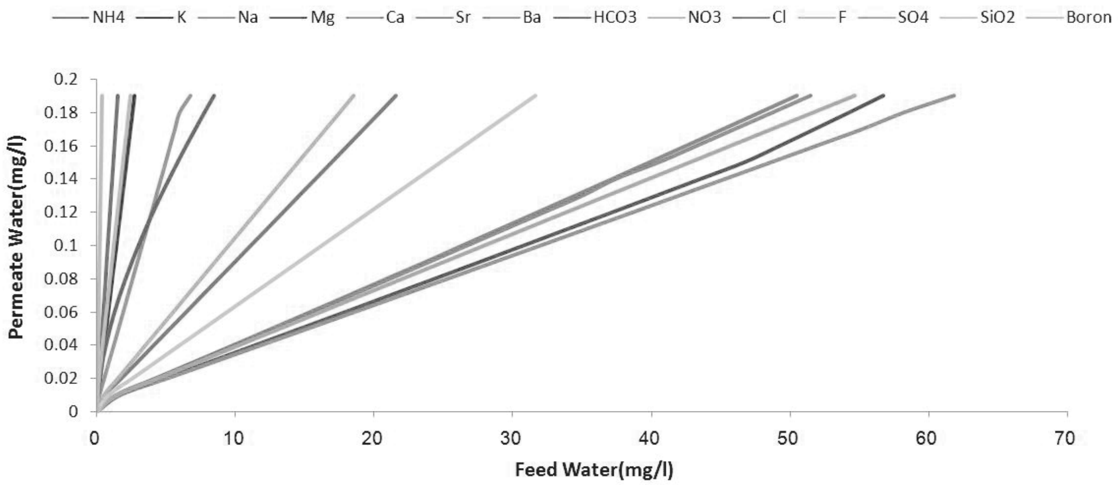

Fig. 1. Sensitivity analysis for all groups.

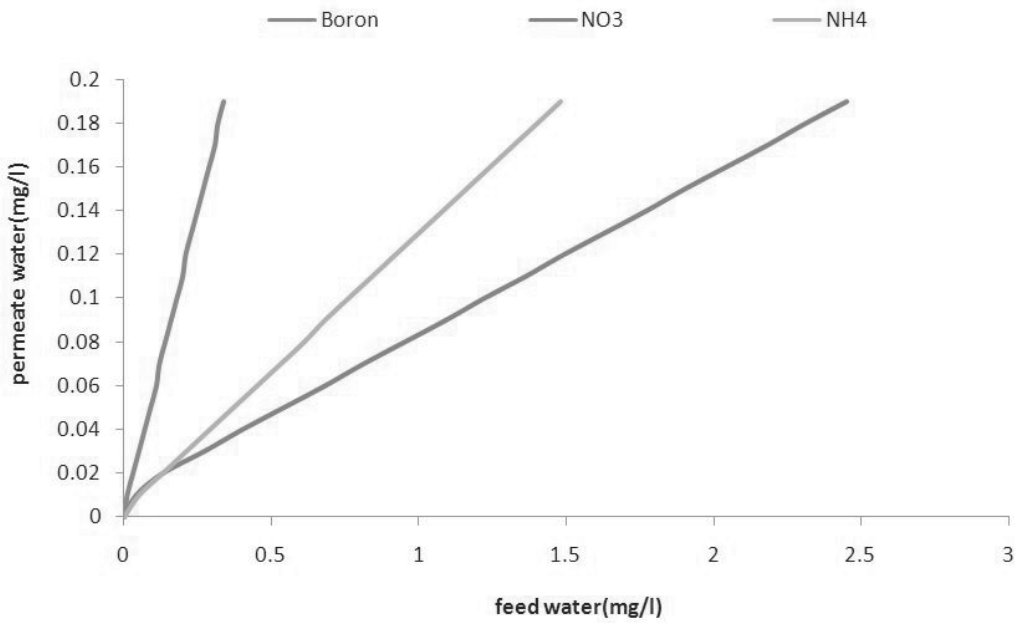

Fig. 2. Sensitivity analysis for group 1.

3. Results

With concern to procedure outlined at second part, for each ion 19 sensitivity gaps were simulated, shown in Table 2.

4. Conclusion

- The shortest gap in the sensitivity analysis is shown by Boron ion and longest gap belongs to Calcium ion. This analysis means at similar conditions the calcium ion would be most eliminated and least is Boron. In fact the order of omitting is from lowest to the highest interval in fallowing order: " Boron, Ammonia, Nitrate, Potassium, Sodium, Bicarbonate, Fluoride, Chloride, Silica, Strontium, Barium, Sulfate, Magnesium, Calcium" which is shown in Table 2. Table 2 provide data likely processed done by reverse osmosis system (ions with higher order would be likely better omitted from feed water).

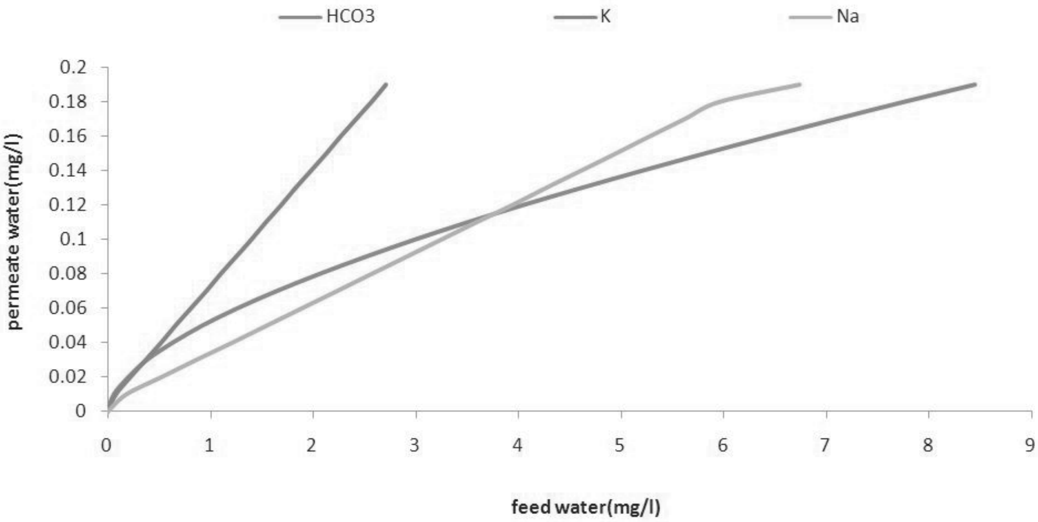

Fig. 3. Sensitivity analysis for group 2.

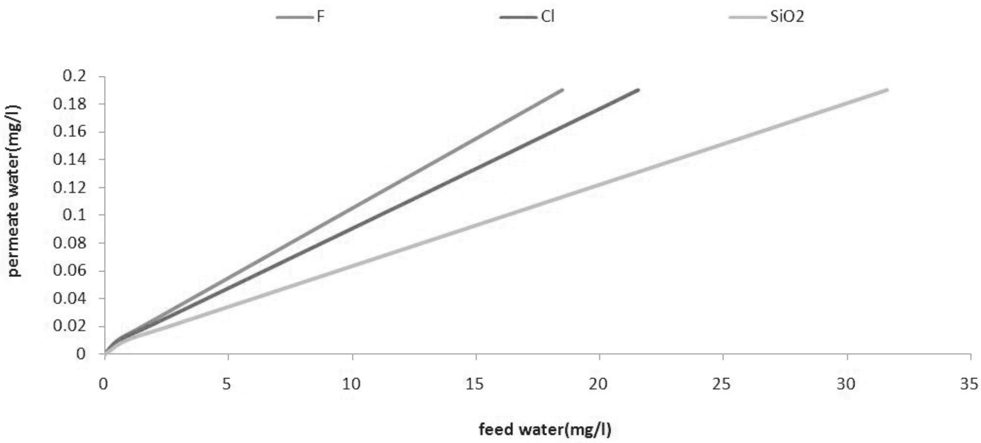

Fig. 4. Sensitivity analysis for group 3.

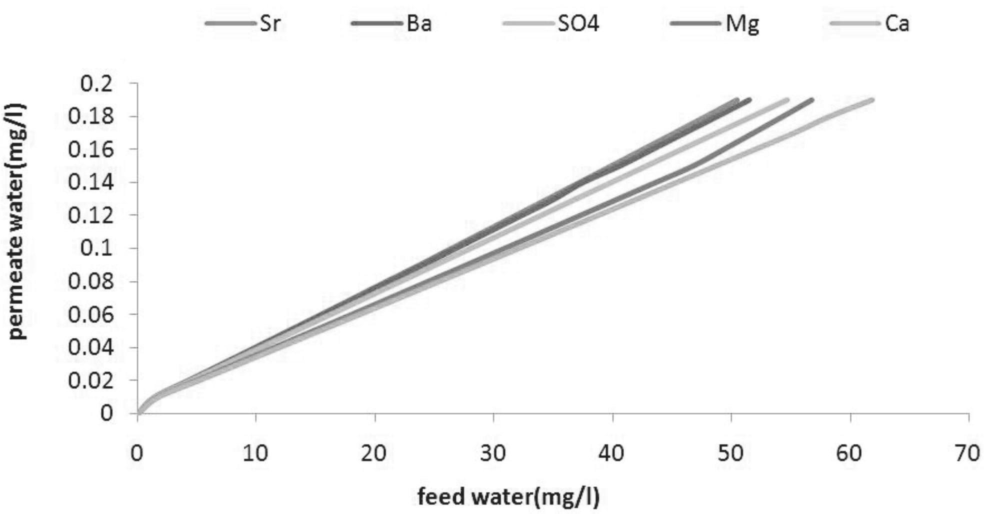

Fig. 5. Sensitivity analysis for group 4.

- For all the ions first gap shows least sensitivity,Table 2 and Figs. 1 to 5.
- Provide analysis which shown percentage the ion eliminated is different in RO system. Ions with similar sensitivity could be categories in four groups, Figs. 2 through 5.
- Sensitivity analysis shows different sensitivity gap at end of the process. In some ions the sensitivity gap is shorter (e.g. Na). With longest gap (e.g. Ca), with no sensitivity (e.g. F) and a few show with constant gap (e.g. K). Shown IN table 2.
- With the current model sensitivity analysis for TDS is impossible. Because ions constitutes similar TDS are different. Process of desalination efficiency with different ions is complex. In the other hand two sample waters with similar TDS; they do not have same efficiency respect to elimination of ions. The research to have an optimum design of desalination system should emphasize on primary ions that constitutes the water samples. Table 2 and fig. 1.
- Based on above results, analysis shows RO system design with permeate water of 20 m^3/h with specification of 16 elements (BW30–400 FR) in 4 parallel pressure vessels are adequate design.

References

[1] N. M. Wade, Distillation plant development and cost update, Desalination, 136, 2001, pp. 3–12.
[2] H. Cooley, P. H. Gleick, G. Wolf, Desalination with grain of salt, Pacific institute, 2006.
[3] Economic and technical assessment of desalination technologies in Australia: with particular reference to national action plan priority regions, Department of agriculture, fisheries and forestry-Australia, 2002.
[4] Energy options for water desalination in selected ESCWA member countries, Economic and social commission for western Asia, United Nation, 2001.
[5] Improvement of worldwide water shortage, JAIF, 2007.
[6] A. M. Munro, Use of chemicals in desalination processes, IDA, 2007.
[7] Seawater desalination feasibility study, PUD NO.1 of Jefferson County, 2007.
[8] Using desalination technologies for water treatment, U.S. congress, office of technology assessment, 1988.
[9] T.Younos, The feasibility of using desalination to supplement drinking water supplies in eastern Virginia, Virginia water resource research center, 2004.
[10] Seawater desalination in California, California Costal Commission, 1993.
[11] I. C. Watson, O.J. Morin, L. Henthorne, (3rdEd), Desalting handbook for planners, RosTek Association Inc, Tampa, Florida, 2003.
[12] S.W. Tinker, J. A. Jackson, A desalination database for Texas, Texas water development board, 2006, pp. 2–29.
[13] Guidelines for integrated water management, National University of Athens, 2005, pp. 13–29.
[14] V. Sabteli, G. Fiorenza, D. Marano, Technical status report on solar desalination and solar cooling, New generation of solar thermal systems, 2005, pp. 59–62.
[15] Word wide desalting plants inventory, Wangnick/GWI, Oxford, England, 2005.
[16] D.H. Furukawa, An introduction to desalination, AMBAG desalination workshop, Monterey, California, 2004.
[17] S.A. Avlonitis, Optimization of the Design and Operation of Seawater RO Desalination Plants, Separation Science and Technology 40, 2005, pp. 2663–2678.
[18] J. Redondo, M. Busch, J. De Witte, Boron removal from seawater using FILMTEC™ high rejection SWRO membranes, Desalination, 156, 2003, pp. 229–238.
[19] J. Chen, G. Li, Marine reverse osmosis desalination plant-a case study, Desalination, 174, 2005, pp. 299–303.
[20] V. Francois, M. Francois, B. Philippe, A. Emmanuelle, Innovative design and multi-objective optimization of hybrid reverse osmosis and muliti-stage flash desalination plants, Veolia Environnement, Water Research Center, 2006.
[21] B.L. Hackman, Membrane technologies for nitrate and atrazine removal from a surface water source, WMRC, Illinois department of natural resources, 1999.
[22] R.W. Holloway, Forward Osmosis for Concentration of Anaerobic Digester Centrate, Master Thesis, University of Nevada, Reno, 2006.
[23] Optimization of the coupling of nuclear reactors and desalination systems, IAEA, 2005.
[24] A. Karameldin, M.S. Saadaw, Seawater feed reverse osmosis preheating appraisal, Part I: leading element performance, International Journal of Nuclear Desalination, 2 (2006) 74–88.
[25] J. Macharg, R. Truby, West coast researchers seek to demonstrate SWRO affordability, Desalination & Water Reuse,14 (2004) 10–18.
[26] D. Manolakos, S. Kyritsis, J. Karagianis, P. Soldatos, Cost Analysis of an Autonomous Low-Temperature Solar Rankine Cycle System for Reverse Osmosis Desalination, WSEAS Int. Conf. on environment, ecosystems and development, Venice, Italy, (2005), pp. 266–271.
[27] K. Moore, Treatment of arsenic contaminated groundwater using oxidation and membrane filtration, Master Thesis, University of Waterloo, 2005.
[28] S. Nisan, B. Commercon, S. Dardour,A new method for the treatment of the reverse osmosis process, with preheating of the feed water, Desalination, 182 (2005) 483–495.
[29] C. Moody, B. Garrett, E. Holler, Pilot investigation of slow sand filtration and reverse osmosis treatment of central Arizona project water,U.S department of the interior, bureau of reclamation, 2002.
[30] J. A. Redondo, A. Casanas, Designing seawater RO for clean and fouling RO feed desalination experiences with the FilmTec SW30HR-380 and SW30HR-320 elements technical-economic review, Desalination, 134 (2001) 83–92.
[31] F. Reverberi, A. Gorenflo, Three years operational experience of a spiral-wound SWRO system with a high fouling potential feed water, Desalination, 203 (2007) 100–106.
[32] M. Thomason, M. Miranda, J. Gwilliom, A. Rowbottom, I. Draisey, Battery less photovoltaic reverse osmosis desalination system, CREST & Duals Ltd., 2001.

[33] A. M. Thomson, Reverse osmosis desalination of seawater powered by photovoltaic without batteries, Doctoral Thesis, Loughborough University, 2003.
[34] V. Verbeek, From Concept Design to Installation and Commissioning, Energy Recovery for SWRO in Singapore, International Desalination Association World Congress on desalination and water reuse, Swissotel, Singapore, 2005.
[35] Y. Zhao, J. S. Taylor, Assessment of ASTM D 4516 for evaluation of reverse osmosis membrane performance, Desalination, 180 (2005) 231–244.
[36] Y. Zhao, Modelling of membrane solute mass transfer in NF/RO membrane systems,Doctoral Thesis, University of Central Florida, 2004.
[37] A.S. Nafey, H.E.S. Fath, A.A. Mabrouk, A new visual package for design and simulation of desalination processes, Desalination, 194 (2006) 281–296.
[38] Producing ultra pure water, FILMTEC Reverse Osmosis Membrane, 1997.
[39] ROSA 6 help, FILMTEC Reverse Osmosis Membrane, 2007
[40] Technical Manual, FILMTEC Reverse Osmosis Membrane, 2005.
[41] Product information, FILMTEC Reverse Osmosis Membrane, 2008.