World Academy of Science, Engineering and Technology
International Journal of Chemical and Molecular Engineering
Vol:3, No:9, 2009

Using Reverse Osmosis Membrane for Chromium Removal from Aqueous Solution

S. A. Mousavi Rad, S. A. Mirbagheri, and T. Mohammadi

Open Science Index, Chemical and Molecular Engineering Vol:3, No:9, 2009 publications.waset.org/4078/pdf

***Abstract*—**In this paper, removal of chromium(VI) from aqueous solution has been researched using reverse osmosis. The influence of transmembrane pressure and feed concentration on permeate flux, water recovery, permeate concentration, and salt rejection was studied. The results showed that according to the variation of transmembrane pressure and feed concentration, the permeate flux and salt rejection were in the range 19.17 to 58.75 l/m^2.min and 99.51 to 99.8 %, respectively. The highest permeate flux, 58.75 l/m^2.min, and water recovery, 42.47 %, were obtained in the highest pressure and the lowest feed concentration. On the other hand, the lowest permeate concentration, 0.01 mg/l, and the highest salt rejection, 99.8 %, were obtained in the highest pressure and the lowest feed concentration.

***Keywords*—**Aqueous solution, Chromium, Removal, Reverse osmosis.

I. Introduction

CHROMIUM is one of the most dangerous inorganic water pollutants. It is constantly released into the aquatic environment by natural processes (mainly by volcanic activity and weathering of rocks) and by anthropic sources, which in the last twenty years have become of leading importance in the worldwide emission balance of these substances [1,2]. In aquatic systems, chromium exists primarily in either the trivalent [Cr(III)] or hexavalent [Cr(VI)] states [3]. The trivalent form is an essential nutrient [4]. The hexavalent form, which is presented as either dichromate ($Cr_2O_7^{2-}$) or as chromate $(CrO_4)^{2-}$, is toxic, carcinogenic, and mutagenic in nature. It is highly mobile in soil and aquatic system and also is a strong oxidant capable of being adsorbed by the skin [5]. Clear evidence indicates that exposure to certain levels of Cr(VI) can result in significant human health and ecological risks. Cr(VI) has been reported to be responsible for lung cancer, chrome ulcers, nasal septum perforation, brain damage, and kidney damage. Chromium and its salts find extensive use in photography, chromium plating, textile manufacture, tanning of leather, manufacturing green varnishes, paints, inks, glasses for porcelain, etc [6]. To meet environmental regulations, effluents or water contaminated with heavy metals such as chromium(VI) must be treated before discharge. Based on Iranian National Discharge Standard, the maximum allowable concentration in effluent discharge is 0.1 mg/lit for hexavalent chromium.

The traditional means to separate Cr(VI) from wastewaters are chemical reduction, precipitation, evaporation and ion exchange. Although ion exchange resins can substantially remove metal ions, they do not show mechanical strength because of swelling of polymeric skeleton and low selectivity. In precipitation process, Cr(VI) is reduced to Cr(III), followed by precipitation of Cr(III) as $Cr(OH)_3$. However, this process is high in costs and treated water still has high chromium ion concentrations and pollutes surface waters. Gradually, industry is seeking replacement methods from traditional metal recovery and separation techniques to overcome disadvantages. These methods have led to the development of new techniques like adsorption and membrane separation [7]. Membrane separation has become increasingly attractive for the treatment and recovering heavy metals as it is highly efficient, easy to operate and low in cost [8].

Hasan et al. studied The Removal of chromium from aqueous waste solution using liquid emulsion membrane [9]. Covarrubias et al. used FAU-type zeolite membranes for removal of trivalent chromium contaminant from aqueous media [10]. Kulkarni et al. presented a Membrane-Based Hybrid Processes for Removal of Hexavalent Chromium [11]. Covarrubias et al. studied The Removal of chromium from aqueous solution using cellulose acetate and sulfonated poly (ether ether ketone) blend ultrafiltration membranes [12]. Kozlowski et al. studied The Removal of chromium(VI) from aqueous solutions by polymer inclusion membranes [13]. Pilot scale membrane separation of electroplating waste water by reverse osmosis has been studied by X. Chai et al. [14]. The main objective of this study is to demonstrate the efficiency of reverse osmosis membrane for removal of hexavalat chromium from aqueous solution. Also, the influence of transmembrane pressure and feed concentration on the removal process has been studied.

II. Materials and Methods

A. Pilot Plant and Aqueous Solutions

The aqueous solutions were made of $K_2Cr_2O_7$ in the concentrations of 5, 20, 40, 60, 80, 100 mg/l. The pilot plant includes a tank and a feeding pump in feeding section, and a pressure vessel, and a reverse osmosis membrane in treatment

S. A. Mousavi Rad is with the Civil Engineering Department, K. N. Toosi University of Technology, Tehran, P. O. Box 15875-4416 Iran (corresponding author to provide phone:+98-21-88786212; fax:+98-21-88786213; e-mail: amir_mousavirad@sina.kntu.ac.ir).

S. A. Mirbagheri is with Civil Engineering Department, K. N. Toosi University of Technology, Tehran, P. O. Box 15875-4416 Iran (e-mail: mirbagheri@kntu.ac.ir).

T. Mohammadi is with the Chemical Engineering Department, Iran University of Science and Technology, Tehran, P. O. Box 16765-163 Iran (e-mail: torajmohammadi@iust.ac.ir).

Open Science Index, Chemical and Molecular Engineering Vol:3, No:9, 2009 publications.waset.org/4078/pdf

section. All the variables were measured in a time interval of 1 *h*. Both permeate and concentrate flows were mixed and recycled to the feeding tank to reduce the required feed solution. A cold water coil was used to control the feed tank water temperature to about 25 °C. The flow rates and pressures were measured by flow meters and pressure indicators, respectively.

In this study, a spiral wounded type RO membrane model FILMTEC BW30-4040 made of polyamid thin film composite was used. The effective filtration area of the membrane is 7.2 m^2. The membrane maximum operating pressure and temperature are 41 bar and 45 °C, respectively. At 2000 ppm NaCl, 15.5 bar pressure, and 25 °C temperature, the net water permeate flux of the membrane is 9.1 m^3/d.

The schematic diagram of the reverse osmosis membrane is demonstrated by Fig. 1. The relationship between the feed flow rate, permeate flow rate, and concentrate flow rate is presented by (1),

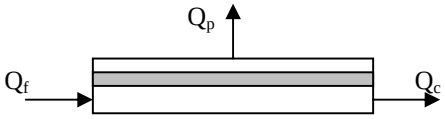


Fig. 1 Schematic diagram of the reverse osmosis membrane

$$Q_f = Q_p + Q_C \quad (1)$$

where Q_f (l/min) is the feed flow rate, Q_c (l/min) is the concentrate flow rate, and Q_p (l/min) is the permeate flow rate.

The permeate fluxes for RO membrane are calculated by (2),

$$Jp = Qp/A \quad (2)$$

where J_p (l/m^2.min) is the permeate flux, Q_p (l/min) is the permeate flow rate, and A (m^2) is the effective area of membrane.

Water recovery efficiency of the membrane is defined by (3),

$$WR = Qp/Qf * 100 \quad (3)$$

where WR (%) is water recovery efficiency, Q_p (l/min) is permeate flow rate, and Q_f (l/min) is feed flow rat.

Separation capacity of ions by a membrane express as Salt Rejection (SR) which is related to membrane selectivity in a specific operation condition [16]. Salt rejection is opposite of salt passage, and is defined by (4),

$$SR = 100 * (1 - C_p / C_f) \quad (4)$$

where SR (%) is salt rejection, C_p (mg/l) is permeate concentration, and C_f (mg/l) is feed concentration.

B. Test Method

Chromium test was done based on photo chromic method by using Lovibond spectrophotometer model PC-Spectro, applying 542 nm wavelengths with pre-prepared reagents. Temperature, PH, and conductivity were measured based on Standard Method for Water and Wastewater Examination, Method No. 2550, 4500-H+, 2510, respectively, by using MARTINY pH/conductivity meter model Mi805 [15].

III. Result and Discussion

On a pilot scale, the influence of transmembrane pressure and feed concentration on permeate flux, water recovery, permeate concentration, and salt rejection was investigated.

Table I demonstrates the flow rates, permeate fluxes and water recovery efficiencies for tests 1 to 30.

TABLE I
Flow Rates, Permeate Fluxes, and Water Recoveries

Test	Variables		Results				
	C_f (mg/l)	Pressure (bar)	Q_f (l/min)	Q_p (l/min)	Q_c (l/min)	J_p (l/m^2h)	WR (%)
1		6	29.7	2.4	27.3	20	8.08
2		9	28.25	3.55	24.7	29.58	12.57
3	5	12	24.55	4.75	19.8	39.58	19.35
4		15	20.55	5.85	14.7	48.75	28.47
5		18	16.6	7.05	9.55	58.75	42.47
6		6	29.7	2.4	27.3	20	8.08
7		9	28.25	3.55	24.7	29.58	12.57
8	20	12	24.4	4.7	19.7	39.17	19.26
9		15	20.4	5.8	14.6	48.33	28.43
10		18	16.5	7	9.5	58.33	42.42
11		6	29.55	2.35	27.2	19.58	7.95
12		9	28.1	3.5	24.6	29.17	12.45
13	40	12	24.4	4.7	19.7	39.17	19.26
14		15	20.4	5.8	14.6	48.33	28.43
15		18	16.5	7	9.5	58.33	42.42
16		6	29.55	2.35	27.2	19.58	7.95
17		9	28.1	3.5	24.6	29.17	12.45
18	60	12	24.4	4.7	19.7	39.17	19.26
19		15	20.4	5.8	14.6	48.33	28.43
20		18	16.45	6.95	9.5	57.91	42.25
21		6	29.55	2.35	27.2	19.58	7.95
22		9	28.1	3.5	24.6	29.17	12.45
23	80	12	24.4	4.7	19.7	39.17	19.26
24		15	20.3	5.75	14.55	47.91	28.32
25		18	16.45	6.95	9.5	57.91	42.25
26		6	29.4	2.3	27.1	19.17	7.82
27		9	27.95	3.45	24.5	28.75	12.34
28	100	12	24.3	4.65	19.65	38.75	19.13
29		15	20.3	5.75	14.55	47.91	28.32
30		18	16.45	6.95	9.5	57.91	42.25

Figs. 2 and 3 show the influence of transmembrane pressure on permeate fluxes and water recoveries in different feed concentrations. Increasing the transmembrane pressure caused to increase the permeate flux and water recovery, as Table I and Figs. 2 and 3.

Figs. 4 and 5 show the influence of feed concentration on permeate flux and water recovery in different transmembrane pressures. Increasing the feed concentration caused to decrease the permeate flux and water recovery, as Table I and Figs. 4 and 5.

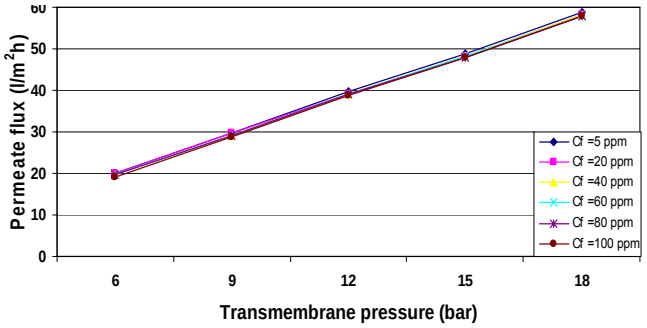


Fig. 2 The influence of pressure on permeate flux

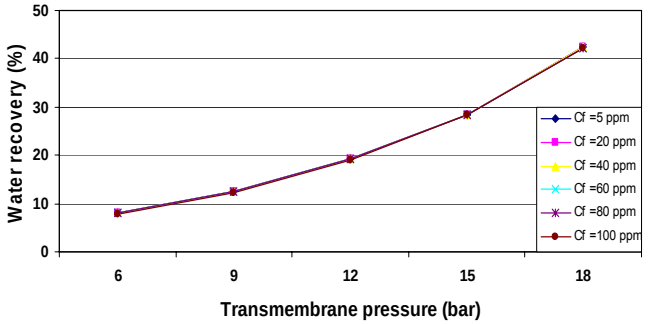


Fig. 3 The influence of pressure on water recovery

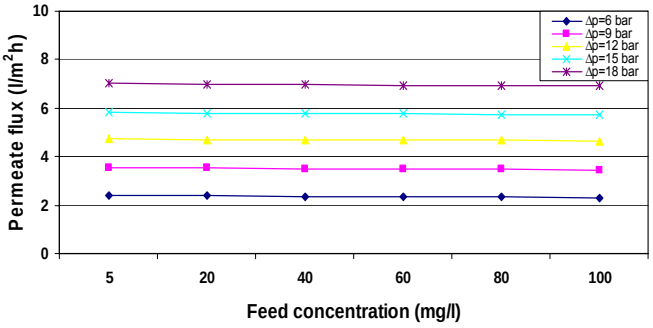


Fig. 4 The influence of feed concentration on permeate flux

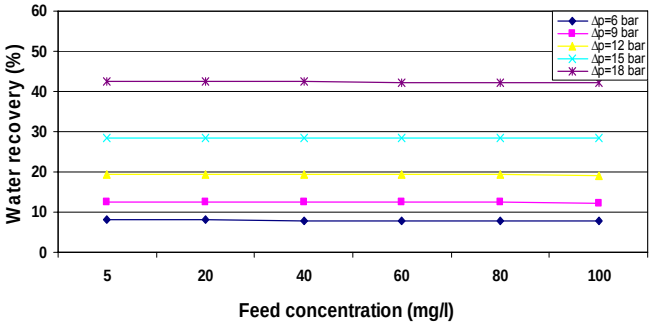


Fig. 5 The influence of feed concentration on water recovery

Table II shows the permeate concentrations and salt rejections for tests 1 to 30.

TABLE II
PERMEATE CONCENTRATION AND SALT REJECTION

Test	Variables		Results	
	C_f (mg/l)	Pressure (bar)	C_p (mg/l)	SR (%)
1	5	6	0.01	99.8
2		9	0.01	99.8
3		12	0.01	99.8
4		15	0.01	99.8
5		18	0.01	99.8
6	20	6	0.06	99.7
7		9	0.04	99.8
8		12	0.04	99.8
9		15	0.04	99.8
10		18	0.04	99.8
11	40	6	0.18	99.55
12		9	0.14	99.65
13		12	0.12	99.7
14		15	0.1	99.75
15		18	0.09	99.77
16	60	6	0.29	99.52
17		9	0.21	99.65
18		12	0.18	99.7
19		15	0.15	99.75
20		18	0.14	99.77
21	80	6	0.39	99.51
22		9	0.29	99.64
23		12	0.24	99.7
24		15	0.2	99.75
25		18	0.19	99.76
26	100	6	0.49	99.51
27		9	0.37	99.63
28		12	0.3	99.7
29		15	0.25	99.75
30		18	0.23	99.77

Figs. 6 and 7 show the influence of transmembrane pressure on permeate concentrations and salt rejections in different feed concentrations. Increasing the transmembrane pressure resulted in decreasing the permeate concentration and increasing salt rejection, as Table II and Figs. 6 and 7.

Figs. 8 and 9 show the influence of feed concentration on permeate concentrations and salt rejections in different transmembrane pressures. Increasing the feed concentration resulted in increasing the permeate concentration and decreasing salt rejection, as Table II and Figs. 8 and 9.

Open Science Index, Chemical and Molecular Engineering Vol:3, No:9, 2009 publications.waset.org/4078/pdf

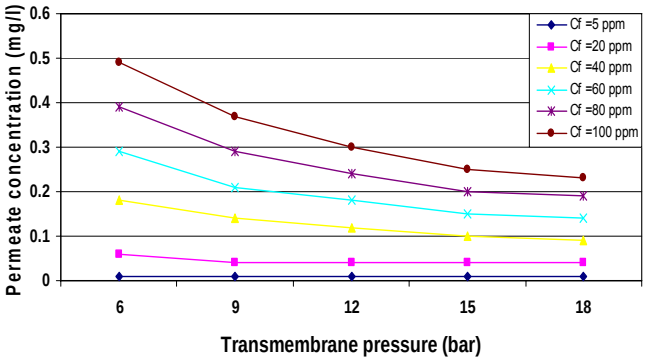


Fig. 6 The influence of pressure on chromium concentration in permeate flow

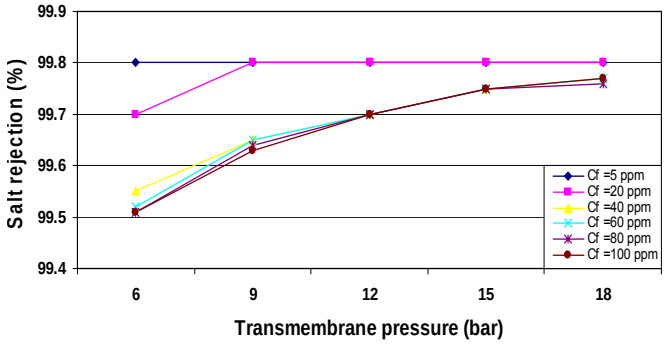


Fig. 7 The influence of transmembrane pressure on salt rejection

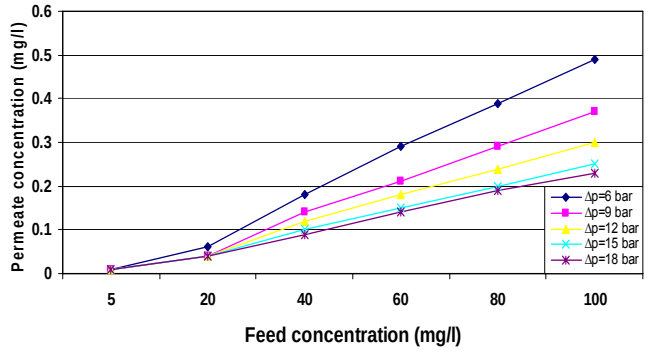


Fig. 8 The influence of feed concentration on chromium concentration in permeate flow

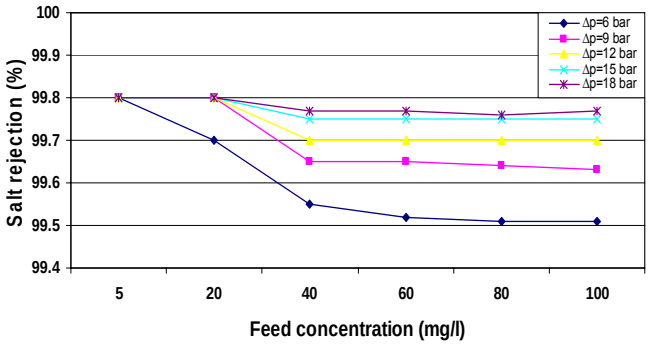


Fig. 9 The influence of feed concentration on salt rejection

The highest permeate flux and water recovery were equal to 58.75 l/m^2.min and 42.47 %, respectively, in the highest pressure of 18 bar and the lowest feed concentration of 5 mg/l, as Table I. The lowest chromium concentration in permeate flow and the highest salt rejection were equal to 0.01 mg/l and 99.8 %, respectively, in the highest pressure of 18 bar and the lowest concentration of 5 mg/l, as Table II.

IV. Conclusion

Removal of Chromium(VI) from aqueous solution has been studied using RO membrane. The influence of transmembrane pressure and feed concentration on permeate flux, water recovery, permeate concentration, and salt rejection was investigated. The results showed that the increasing the transmembrane pressure in the range 5 to 18 bar caused: 1. Increasing the permeate flux and water recovery in different feed concentrations. 2. Decreasing the permeate concentration and increasing salt rejection in different feed concentrations. On the other hand, increasing the feed concentration in the range 5 to 100 mg/l caused: 1. Decreasing the permeate flux and water recovery in different transmembrane pressures 2. Increasing the permeate concentration and decreasing salt rejection in different transmembrane pressures. Eventually, the highest permeate flow rate and water recovery were equal to 58.75 l/min and 42.47 %, respectively, in the highest pressure of 18 bar and the lowest feed concentration of 5 mg/l. The lowest permeate concentration and the highest salt rejection were equal to 0.01 mg/l and 99.8 %, respectively, in the highest pressure of 18 bar and the lowest concentration of 5 mg/l.

Acknowledgment

Financial support to this study by K.N. Toosi University of Technology and Rosoub Ab Company is gratefully acknowledged. S. A. Moosavi Rad thanks to Mrs. R. Bazazzadeh for her help in experiences.

References

[1] N. Serpone, E. Borgarello, E. Pelizzeti, E. Schiavello (Eds.), Photocatalysis and Environment, Kluwer Academic, The Netherlands, 1988.
[2] J. O. Nriagu, J. M. Pacyna, Quantitative assessment of worldwide contamination of air, water and soils by trace metals, Nature (Lond., UK) 333 (6169), 134–139, 1988.
[3] P. Rana-Madaria, M. Nagarajan, C. Rajagopal, and B. S. Garg, Removal of Chromium from Aqueous Solutions by Treatment with Carbon Aerogel Electrodes Using Response Surface Methodology, Industrial and Engineering Chemistry Research 44 (17), 6549-6559, 2005.
[4] G. Rojas, J. Silva, J.A. Flores, A. Rodriguez, M. Ly,H.Maldonado, Adsorption of chromium onto cross-linked chitosan, Seperation Purification Technology 44, 31–36, 2005.
[5] I.B. Singh, D.R. Singh, Cr(VI) removal in acidic aqueous solution using iron-bearing industrial solid wastes and their stabilisation with cement, Environmental Technology 23, 85–95, 2002.
[6] C. Ahmed Basha, K. Ramanathan, R. Rajkumar, M. Mahalakshmi, and P. Senthil Kumar, Management of Chromium Plating Rinsewater Using Electrochemical Ion Exchange, Industrial and Engineering Chemistry Research 47 (7), 2279-2286, 2008.
[7] H. Park, and L. L. Tavlarides Adsorption of Chromium(VI) from Aqueous Solutions Using an Imidazole Functionalized Adsorbent, Industrial and Engineering Chemistry Research 47 (10), 3401-3409, 2008.

Open Science Index, Chemical and Molecular Engineering Vol:3, No:9, 2009 publications.waset.org/4078/pdf

[8] J. Qin, M. Wai, M. Oo, F. Wong, A feasibility study on the treatment and recycling of a wastewater from metal plating, Journal of Membrane Science 208, 213-221, 2002.
[9] M.A. Hasana, Y.T. Selima, K.M. Mohamed, Removal of chromium from aqueous waste solution using liquid emulsion membrane, Journal of Hazardous Materials, 2009.
[10] Cristian Covarrubias a, Rafael Garc´ıa, Ren´an Arriagada, Jorge Y´anez, Harikrishnan Ramananb, Zhiping Lai b, Michael Tsapatsis, Removal of trivalent chromium contaminant from aqueous media using FAU-type zeolite membranes, Journal of Membrane Science 312, 163–173, 2008.
[11] P. S. Kulkarni, V. Kalyani, and V. V. Mahajani, Removal of Hexavalent Chromium by Membrane-Based Hybrid Processes, Industrial and Engineering Chemistry Research 46 (24), 8176-8182, 2007.
[12] G. Arthanareeswaran, P. Thanikaivelan, N. Jaya, D. Mohana,, M. Raajenthiren, Removal of chromium from aqueous solution using cellulose acetate and sulfonated poly(ether ether ketone) blend ultrafiltration membranes, Journal of Hazardous Materials B139, 44–49, 2007.
[13] C. Kozlowski, W. Walkowiak, Removal of chromium(VI) from aqueous solutions by polymer inclusion membranes, Water Research 36, 4870–4876, 2002.
[14] X. Chai, G. Chen, P. Yue, Y. Mi, Pilot scale membrane separation of electroplating waste water by reverse osmosis, Journal of Membrane Science 123, 235-242, 1997.
[15] American Water Works Association, Standard Methods for the Examination of Water and Wastewater, 21th ed. APHA, Washington, DC, 2005.
[16] M. C. Porter, Handbook of Industrial Membrane Technology, Noyes Publications, NJ, 1990.

Open Science Index, Chemical and Molecular Engineering Vol:3, No:9, 2009 publications.waset.org/4078/pdf