Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

Second Engineering Scientific Conference
College of Engineering –University of Diyala
16-17 December. 2015, pp. 893-908

REMOVAL OF LEAD, COPPER AND NICKEL IONS FROM WASTEWATER BY FORWARD OSMOSIS PROCESS

Ahmed A. Mohammed [1], Ahmed Faiq Al – Alawy [2], Tamara Kawther Hussein [3]

[1, 2] Assistant Professor, [3] Lecturer
[1] Environmental Engineering Department, [2] Chemical Engineering Department
[1,2] College of Engineering-University of Baghdad
[3] Environmental Engineering Department, College of Engineering-University of Al - Mustansiryiah

ABSTRACT: - In this study the application of a novel forward osmosis (FO) process for the removal of Pb(II), Cu(II), and Ni(II) metal ions from wastewater is briefly described. Polyamide (thin film composite (TFC))used as flat sheet forward membrane for heavy metal rejection under orientation membrane of active layer facing feed solution and using NaCl of different concentration as the draw solution. The operating parameters studied were draw solutions concentration (5 - 100 g/l), feed solutions concentration (5 - 200 mg/l), pH of feed solution (4 - 8), constant pressure and temperature were maintained at 0.2 bar and 25 $^{\circ}$C respectively. It was found that the water flux increases with increasing draw solution concentration, and decreases with increasing feed solution concentration and pH of feed solution. For different type of heavy metal used as feed solution, the order of water flux was Pb^{+2}> Cu^{+2}> Ni^{+2}. For binary and ternary feed solution, the water flux decreased with time and increasing with the concentration of feed solution due to decreasing of driving force. Forward osmosis can be used to recover water from wastewater contaminated by heavy metals with a rejection efficiency more than 99%, 97% and 87% for Pb^{+2}, Ni^{+2}, and Cu^{+2}metal ions respectively.

Keywords: forward osmosis; heavy metal wastewater; membranes separations.

1-INTRODUCTION

Water pollution is nowadays a matter of deep apprehension. Hazardous metals are discharged into the environment causing soil and water pollution, which must be removed before reuse of the water or it's discharged to the environment, Mohammed et al., 2014. Heavy metal such as lead, copper, nickel, cobalt, cadmium and zinc are naturally occurring element, small amounts of these elements are common in our environment and they are actually necessary for human health, but large amounts of them may cause acute or chronic toxicity, Rengaraj and Moon, 2002; Al- Ghouti et al., 2004.Heavy metals are released by various industries such as pulp; paper mills, petrochemical, fertilizers, motor vehicles, steel works and inorganic chemicals, etc., Abed, 2011. The removal of heavy metal contaminants from wastewater is one of the most important environment issues being faced the world over. The most common methods for the removal of metal ions from wastewater include: coagulation - flocculation, chemical precipitation, adsorption, ion exchange, and flotation. However, these methods have certain disadvantage such as incomplete metal removal, high reagent and energy requirement, generation of toxic sludge or other waste products that require disposal. The hazardous waste generated from mining and smelting operation also need to be decontaminated before entering the ecosystem, Kargar and Yahyaabadi, 2012.Osmosis is the diffusion of water through a semi permeable barrier from a solution of low solute concentration (high water potential) to a solution with high solute concentration (low water potential). The inherent energy of this natural process is known as the chemical potential, or specifically the water potential, due to the difference in concentration of the two solutions, Hsiang, 2011.

The forward osmosis (FO) process is a recently emerging technology for the membrane separation process, including desalination. Since the process is based on the natural osmotic process using a concentration gradient across a semi-permeable membrane, it has been termed a novel process, particularly for desalination as it does not require high pressure such as in the RO process. FO process has been said to have the edge over the RO process in terms of energy consumption and fouling resistance, Tang et al., 2010.The advantage of FO technology include, Low fouling propensity, low pressure reduces effects of fouling, wide range of feed solutions, reduced power and design costs (i.e. low pressure).The draw solute must have the following characteristics: The selected draw solution must require low energy for regeneration or reconcentration, have a high osmotic pressure, must be easily separated from the pure product water, must be non-toxic and un expensive, must be chemically inert to the membrane, Chien and How, 2008 and Qasim, 2013.

The main aim of this work is to investigate the efficiency of forward osmosis (FO) process as a new application for the removal of Pb^{+2}, Cu^{+2}, and Ni^{+2} ions from wastewater. In this work using NaCl as draw solution to extract water from effluent across thin film composite (TFC) a semi – permeable membrane, the effect of different parameters such as draw solution concentration, feed solution concentration, and pH of feed solution on water flux and study the efficiency of the forward osmosis process on the rejection of lead, copper and nickel ions from wastewater.

2- VAN'T HOFF'S LAW

Van't Hoff's Law is strictly true only for very dilute solutions (ideal solution). Van't Hoff's Law is often used to estimate the osmotic pressures of solutions, Thain, 1967.

$$\pi = \Phi \, i R_g T C \qquad (1)$$

where π is the osmotic pressure (bar), i is number of dissociated ions per molecule (van't Hoff factor), R_g is the universal gas constant (liter bar /g. K), T is the temperature (K), C is the concentration of solute (g/l), Φ is osmotic coefficient (for ideal solution, $\Phi = 1$).

3- RECOVERY AND REJECTION PERCENTAGE

The recovery factor measures how much of feed is recovered as permeate. It is reported as a percentage. The recovery of the membrane was calculated by dividing the overall volume of permeate by the initial volume of feed solution, Al-Alawy, 2000.

$$Y = \left(\frac{V_P}{V_F}\right) \times 100 \qquad (2)$$

Where V_P is the overall volume of permeate and $V_F$is the initial volume of feed solution. The measure of membrane selectivity is solute rejection, the ratio of solute rejected by a membrane to the solute in the feed. It is the most common method of evaluating a membrane's ability to separate solute, because the determination is simple and can be done as accurately in the field as in the laboratory, Hasan 2008 and Yip et al., 2010.

$$R\% = \left(1 - \frac{C_P}{C_F}\right) * 100 \qquad (3)$$

Where C_F is the concentration of a specific component in the feed solution and C_P is the concentration of the same specific component in the product stream leaving the membrane system.

4. EXPERIMENTAL WORK

4.1 Feed and Draw Solutions

Samples having concentration of lead Pb(II), nickel Ni(II), and copper Cu(II) were prepared by dissolving the required amount of lead nitrate $Pb(NO_3)_2$, nickel chloride $NiCl_2$ and copper sulfate hydrates $CuSO_4.5H_2O$ in deionized water (DI), of 3-8 µS/cm conductivity. Solution pH was adjusted (4-8) by adding 0.1 M HCL or 0.1 M NaOH as required, and then solutions were mixed using a stirrer at an agitation speed of 1000 rpm for 15 min. The total feed solution volume was 2 liters. Deionized water of 3-8 µs/cm conductivity, was used for preparing sodium chloride (NaCl) with concentration of 5, 25, 50 and 100 g/l, and then solution was mixed using a stirrer at an agitation speed of 1000 rpm for 15 min. The total draw solution volume was 2 liters. This sodium chloride NaCl was selected in preparation of draw solutions because it has low molecular weight, low viscosity, high solubility, high osmotic pressure that can be given by this solution, nontoxic, easily and economically separated and recycled.

4.2 Forward Osmosis Cell

Thin film composite membrane elements (TFC) was used as flat sheet module for the forward osmosis experiments. TFC membrane including of three layers: a polyester support web (120µm), a microporous polysulfone inter layer (40µm), and an ultra-thin polyamide barrier layer (0.2 µm) at the top surface each layer is fitted to specific requirements. The specifications of the membrane module are membrane active area 151.2 cm^2, salt rejection (96 – 99 %), maximum operating pressure 6.9 Mpa, maximum operating temperature 45 $^{\circ}C$, free chlorine tolerance <0.1 mg/l and pH range for continuous operation (2 - 11). Experiments were conducted using a laboratory-scale FO system consists of two cylinders with a capacity of 5 liters were used as a feed and draw solution vessels, two high pressure pumps (positive displacement, diaphragm pump) were used. Both used to pump the draw solution and feed solution from vessels to direct osmosis element using inlet pressure 29 psi, two calibrated flow meters: one was used to measure the volumetric flow rate of feed solution and the other was used to measure the volumetric flow rate of draw solution each of ranged (30 - 240 l/h), a pressure gauge (range of 0-2 bar gauge) was used in the feed solution to indicate the feed solution pressure. The forward osmosis cell was consisting of two semi-cells which were made of Teflon. It was designed with two flow channels and diameter of each channels was139 mm and the effective membrane area of 151.2 cm^2. The pH of feed solution was adjusted to the required value by addition of (NaOH) or (HCl), and acidity of feed solution was measured using pH meter (Model 2906, Jenway Ltd, UK). Digital laboratory conductivity meter is used to measure the concentration of the draw solutions, range ($0\text{-}2 \times 10^6$ µS/cm), also the concentration of the metal in the feed solution was measured by Atomic Absorption Spectrometry (AAS) (Buck 210/211, U.S.A., Perkin Elmer, Sr.Nr:1159A). Stirrer (0 – 2000 rpm, England) was used to mixing solutions. A digital balance with 4 decimal points (Sartorius BP 3015 max. 303 g, d=0-1 mg) was used to measure the samples weight in experiments.

4.3Experimental Procedure

In typical orientation of forward osmosis process, the draw solution was placed against the support layer and the feed solution was on the active layer. The feed and draw solutions were operated in a co-current flow configuration (feed and draw solution flowing tangential to the membrane in the same direction). This mode of operation provides constant $\Delta\pi$ along the membrane module and makes the process more efficient. The outlet streams of feed and draw solutions were recycled back to the main vessels. All experiments were carried out with applying a pressure of 0.2 bar gauge across the membrane sheets in the feed side. The time of experiment was 2 hours. For every 0.25 hour, measuring the increase in volume of the draw solution (DS) and comparing it with the reduction in the FS volume. Metal concentration in FS outlet was measured using Atomic Absorption Spectrometry (AAS) and NaCl concentration in DS outlet was measured using conductivity meter. Fig. 1 shows the schematic diagram of forward osmosis apparatus used in laboratory of chemical engineering department – University of Baghdad. For cleaning the membrane, osmotic backwashing was used to remove metal that had accumulated on or in the pores of the membrane. In the backwashing process, the direction of water permeation across the semipermeable membrane was reversed and the DS was replaced with deionized water and FS was replaced with 25 g/l of brine, Hickenbottom, 2013. Deionized water flows through draw side channel, the osmotic pressure gradients were formed in an opposite direction and water transport across the membrane from draw side (deionized water) to feed side (brine). Therefore, foulants on the membrane surface are detached by this opposite flow and were removed from the membrane surface. The vessels were drained by mean valves and the whole system was washed up by tap water and distilled water respectively.

5. RESULTS AND DISCUSSION

5.1 Effect of Draw and Feed Solutions Concentration

Figs.2, 3 and 4 show the effect of draw solution concentration (Cd) on water flux with time for Pb(II), Cu(II), and Ni(II) ions as feed solution respectively. From these figures it can be seen that the order of pure water flux is: Jw (Pb(II)) >Jw (Cu(II)) >Jw (Ni(II)) due to that that the osmotic pressure depends on the molecular weight of solute, high molecular weight of feed solution caused low osmotic pressure, this lead to increase driving force and increase water flux since the Molecular weight of $Pb(NO_3)_2$ (M.wt = 331.23)>Molecular weight of $CuSO_4.5H_2O$ (M.wt = 249.68)>Molecular weight of $NiCl_2$ (M.wt = 129.6).When the concentration of draw solution increased, the water permeation across the membrane increased, as a result, the water flux increased, which is attributed to an increase in driving force and water transport through the membrane. This behavior was agreement with, Jui et al., 2012. In the FO process when the feed solution facing the active layer of the membrane and draw solution facing the support layer of the membrane, the water flux decreased with the time and the steady state is reached after 2 h, this attributes to concentration polarization phenomenon on the membrane and diminishes the concentration of draw solution, which confirms what came to, Abdulhakeem et al., 2013. Also increasing draw solution concentration with the time, draw solution outlet concentration decreases and feed solution outlet concentration increase because of the increasing in water transport from feed side to draw side across the membrane Figs.5 to 7 for Pb(II), Ni(II), and Cu(II)respectively. These observations are well agreed with the results of, Chetan and Navin, 2010 and Zghair, 2014. Figs. 8, 9 and 10 show the effect of concentration of NaCl on recovery (Y%) with time for Pb(II), Ni(II), and Cu(II)respectively. The recovery increased with increasing draw solution concentrations due to an increase in the volume of pure water transfer from feed solution to the draw solution across the membrane. These results correspond with the results of the researchers, Ahmed, 2011, and Yaseen, 2013.Figs.11 to 16illustrate the effect of different feed solution concentration (C_f) (Pb(II), Ni(II), and Cu(II)) on water flux, and draw solution outlet concentration. From these figures it can be seen that the water flux decreased with increasing initial feed solution concentration, and draw solution outlet concentration increased with increasing initial feed solution concentration. The increase of feed solution concentration will increase the osmotic pressure of feed solution and decrease of driving force lead to a decrease in water flux with the time. These conclusions correspond with the investigation of, Sangyoup et al., 2010. When the concentration of feed solution increase, the outlet concentration of draw solution increase, this is due to that the permeate water diminishes which lead to a decrease the dilution of draw solution. These results correspond with the investigation of, Hussein, 2009, and Issa, 2011.

5.2 Effect of Initial pH of Feed Solution

The effect of pH solution on osmosis cell for different feed solution [Pb(II), Ni(II), and Cu(II)] are shown in Figs.17 to 22. It is obvious that when the pH of the FS solution decreases, the solubility of dissolved salts increases, Al-Ameer, 2011. This would decrease the rate of salt scaling on the membrane surface which leads to decrease the osmotic pressure and increase the permeate flux. On the contrary increasing pH of solution would accelerate the deposition of salt on membrane surface lead to concentrative external concentration polarization (ECP), this would decreases the permeate flux with time. This conclusion agrees with the investigation of, Cong et al., 2013. Increasing pH of feed solution will decrease water transport through membrane and this will cause an increase draw solution outlet concentration and decrease the feed solution outlet concentration.

5.3 Effect of Binary and Ternary Feed Solution Concentration

Figs. 23 to 25show the effect of different concentration of binary feed solution (Pb^{+2}+Cu^{+2}, Pb^{+2}+Ni^{+2} and Cu^{+2}+Ni^{+2}) on the permeate water flux with the time. The decrease in water flux with increases the concentration of binary feed solution due to decrease in driving force ($\Delta\pi = \pi_{NaCl} - \pi_{binary\ metals}$). On comparing the water flux for binary feed solution with one metal feed solution as shown in Fig.26, its found that the water flux for one metal feed solution higher than the water flux for binary feed solution because the amount of concentrative (ECP) on membrane in binary feed solution more than one metal feed solution. Fig. 27shows the effect of different concentration of ternary feed solution on the permeate water flux with the time. Increasing the concentration of ternary feed solution caused decreasing in water flux due to decreasing in driving force ($\Delta\pi = \pi_{NaCl} - \pi_{ternaey\ metals}$). On comparing the water flux for single feed solution (Pb^{+2}) with binary feed solution (Pb^{+2}+Ni^{+2}) and ternaryfeed solution (Pb^{+2}+Ni^{+2}+Cu^{+2}) as shown in Fig. 28, it's found that:

$Jw_{one\ metal\ feed\ solution} > Jw_{binary\ feed\ solution} > Jw_{ternary\ feed\ solution}$ due to the amount of concentrative ECP on membrane of ternary feed solution > binary feed solution> one metal feed solution.

5.4- Feed Solute Concentration in Permeate and Membrane Rejection Percentage (*R %*) for Single, Binary and Ternary Feed Solution

It is found at experimental condition (NaCl concentration in DS = 25 g/l, metal concentration in FS = 50 mg/l, Temp. of FS & DS = 25 °C and pH of feed=6, Q_d=60 l/hr, Q_d=60 l/hr, p = 0.2 bar) that the concentration of feed solute (heavy metal) in draw solution after 2 hr for single metal solution were ND, 2.782 mg/l, and 1.79 mg/l for Pb^{+2}, Cu^{+2}, and Ni^{+2} respectively. For binary metal solution (Pb^{+2} + Ni^{+2}) the outlet concentration were 0.736, 2.326 mg/l for Pb^{+2},and Ni^{+2} respectively, for binary metal solution (Pb^{+2} + Cu^{+2}) the outlet concentration were 0.26 mg/l, 7.452 mg/l for Pb^{+2},and Cu^{+2} respectively, and for binary metal solution (Cu^{+2} + Ni^{+2}) the outlet concentration were 0.366 mg/l, 1.05 mg/l for Cu^{+2}, and Ni^{+2} respectively. For ternary metal solution (Pb^{+2} + Cu^{+2} + Ni^{+2}) the outlet concentration were 1.906 mg/l, 8.882 mg/l, and 2.554 mg/l for Pb^{+2}, Cu^{+2}, and Ni^{+2} respectively. The rejection percentage (*R %*) is a combination factor between the solute concentration in feed (C_F) and solute concentration in the product (C_P). It is calculated according equation (3).It is found that the membrane rejection percentage (*R %*) after 2 hr for single metal solution were 100 %, 94.436 %, and 96.42 % for Pb^{+2}, Cu^{+2}, and Ni^{+2} respectively. For binary metal solution (Pb^{+2}+Ni^{+2})the rejection percentage *R%* were, 98.528 % and 95.348% for Pb^{+2}, and Ni^{+2} respectively, for binary metal solution (Pb^{+2}+Cu^{+2}) the rejection percentage *R%* were 99.48 % and 85.096 % for Pb^{+2}, and Cu^{+2} respectively, and for binary metal solution (Cu^{+2}+Ni^{+2}) were 99.268 %, and 97.9 %for Cu^{+2}, and Ni^{+2} respectively. For ternary metal solution

(Pb^{+2}+Cu^{+2}+Ni^{+2}) the rejection percentage *R%* were96.188 %, 82.236 %, and 94.892 % for Pb^{+2}, Cu^{+2}, and Ni $^{+2}$ respectively. The salt rejection decreased with increasing in operating time, the explanation for the behavior is that the increasing in metallic concentration will decrease the rejection percentage, because of formation of layer on the membrane surface hinders the back diffusion of the metals from the membrane surface back to the bulk solution. Consequently, created a larger concentration prepared for its diffusion across the membrane and this observation is well agreed with the results by Changwoo et al., 2012.Table 1, 2 and 3 show the feed solute concentration in permeate and membrane Rejection Percentage (*R %*) for single, binary and ternary feed solution.

6. CONCLUSIONS

Forward osmosis can be used to recover water from wastewater contaminated by heavy metals with a rejection efficiency more than 99%, 97% and 87% for Pb(II), Ni(II), and Cu(II) respectively. The order of water flux for heavy metals was lead, copper and nickel respectively. The water flux produced from the osmosis cell increases by increasing the concentration of draw solutions and decreases by increasing the concentration of feed solution, and increasing the pH of feed solution. The effect of draw solution concentration is higher than that of the other variables and the polyamide membrane (TFC) has high rejection percentage for heavy metals. For binary and ternary the water flux decreased with increasing the concentration of feed solution. The water flux for single metal feed solution was more than binary metal solution and the flux of ternary metal feed solution was lower than binary metal solution.

7. REFERENCES

1. Abdulhakeem, A. A., James A. M, Stuart J. K., William E. P., Long D. N., Menachem E., 2013, *Removal of trace organic contaminants by the forward osmosis process*, Separation and Purification Technology, Vol. 103, P. 258–266.
2. Abed, F. I., 2011, *Removal of copper ion from waste water by flotation*, M.Sc. thesis, Baghdad University.
3. Ahmed, B., 2003, "*Osmotic water purification devices*", hydration technology Inc.
4. Al-Alawy, A. F. H., 2000, *Study of The Factors Affecting the Efficiency of Reverse Osmosis Process*, M.Sc. thesis, Baghdad University.
5. Al-Alawy, A. F. H., 2007, *Performance of Manipulated Direct Osmosis in Water Desalination Process,* Ph.D. thesis, Baghdad University.
6. Al-Ameer, A. M.A, 2011, *Dye Removal from Industrial Wastewater Using Membrane Technology*, M.Sc. thesis, Technology University.
7. Al-Ghouti, M. A., Khraiseh, M. A. M., and Tutuji, M., 2004, *Flow injection potentio metric stripping analysis for study of adsorption of n heavy metal ions onto modified diatomite*, Journal of Chemical Engineering., Vol. 104, PP. 83 -91.
8. Changwoo, K., Sangyoup, L., Ho, K. S., Menachem, E., Seungkwan, H., 2012,*Adsorption boron transport in forward osmosis: measurements, mechanisms, and comparison with reverse osmosis*, Journal of membrane science, Vol. 419-420, P. 42-48.
9. Chetan, A. N. and Navin, K. R., 2010, "*Forward osmosis for the concentration of anthocyanin from garciniaindicachoisy*", Separation and Purification Technology, Vol. 71, PP. 144-151.

10. Chien, H. T., and How, Y. N., 2008, *Modified models to predict flux behavior in forward osmosis in consideration of external and internal concentration polarizations*, Journal of Membrane Science, Vol. 324, P. 209-219.
11. Cong, N. N., Shiao, S. C., Thi, H. N., and Kuo, Z. H., 2013,*Exploration of Ethylenediaminetetraacetic Acid Disodium (EDTA-2Na) Salt as novel draw solution for forward osmosis process on dewatering of high nutrient sludge*, Proceedings of the IETEC'13 Conference, Ho Chi Minh City, Vietnam.
12. Hasan, F. M., 2008, *Investigating Polyamide Membrane in Direct Osmosis Process in Cooling Towers*, Ph.D. Thesis, Baghdad University.
13. Hickenbottom, K. L., Hancock, N. T., Hutchings,N. R., Appleton, E. W., Beaudry, E. G., Xu, P., Cath,T. Y.,2013*Forward osmosis treatment of drilling mud and fracturing wastewater from oil and gas operations*, Desalination , Vol. 312, No. 60–66.
14. Hsiang, T. C., 2011, *Modeing and optimization of the forward osmosis process - parameters selection, flux prediction and process application*, Ph.D. Thesis, National University OF Singapore.
15. Hussein, M., 2009, *A study of forward osmosis using various drawing agents*, M.Sc. thesis, Baghdad University.
16. Issa, S. Y., 2011, Water *recovery from brine solution by forward osmosis process*, M.Sc. thesis, Baghdad University.
17. Jui, S. Y., William, A. P., and Menachem, E., 2012, *Coupled reverse draw solute permeation and water flux in forward osmosis with neutral draw solutes*, Journal of Membrane Science, Vol. 392-393, P. 9-17.
18. Kargar. M., and Yahyaabadi, S., 2012, *Adsorption consideration of* Ni^{+2}, Fe^{+2}, Cu^{+2}, Cr^{+2} *and* Co^{+2} *by phosphate and its concentration from solution in isotherm models*, IJRRAS, 10,3, March, PP. 397-407.
19. Mohammad, A. A., Farah, I. A., and Al-musawi, T. J., 2014, *Bisorption of Pb (II) from aqueous solution by spent black tea leaves and separation by flotation*, Desalination and Water Treatment, Doi 10.1080 / 19443994. 2014. 982194.
20. Qasim, M., 2013, "*Performance of forward osmosis using various membranes*" M.Sc. thesis, American University of Sharjah.
21. Rengaraj, S., and Moon, S., 2002, *Kinetics of adsorption of Co (II) removal from water and waste water by ion exchange resins*, Water Resource, Vol. 36,PP. 1783 -1793.
22. Sangyoup, L., Chanhee, B., Menachem, E., and Seungkwan, H. 2010, *Comparsion of fouling behavior in forward osmosis (FO) and reverse osmosis (RO)* , Journal of Membrane Science, Vol. 365, PP. 34-39.
23. Tang, C. Y., She, Q. H., Lay, W. C. L., Wang, R., and Fane, A.G., 2010, *Coupled effects of internal concentration polarization and fouling on flux behavior of forward osmosis membranes during humic acid filtration*, Journal of Membrane Science, Vol. 355, PP. 158–167.
24. Thain, J. F., 1967, *Principles of Osmotic Phenomena*, W Heffer& Sons Ltd, London.
25. Yaseen, F, A, 2013, *Application of forward osmosis process of whey concentration*, M.Sc. thesis, Baghdad University.
26. Yip, N. Y., Tiraferri, A., Phillip, W. A., Schiffman, J. D., and Elimelech, M., 2010, *High performance thin-film composite forward osmosis membrane*, Environmental Science & Technology", Vol. 44, PP. 3812–3818.

27. Zghair, N. H., 2014, *Forward- Reverse osmosis processes for oily waste water treatment*, M.Sc. thesis, Baghdad University.

Table (1): Feed Solute Concentration in Permeate and Membrane Rejection Percentage (*R%*) with the Time for Single Feed Solution

Time (hr)	Conc. of Pb^{+2} (mg/l)	Conc. of Cu^{+2} (mg/l)	Conc. of Ni^{+2} (mg/l)	Rejection (R%) (Pb^{+2})	Rejection (R%) (Cu^{+2})	Rejection (R%) (Ni^{+2})
0.25	ND	2.002	0.175	100 %	95.996 %	99.65 %
1	ND	2.629	0.75	100 %	94.742 %	98.5 %
1.5	ND	2.613	1.375	100 %	94.774 %	97.25 %
2	ND	2.782	1.79	100 %	94.436 %	96.42 %

Table (2): Feed Solute Concentration in Permeate and Membrane Rejection Percentage (*R %*) with the Time for Binary Feed Solution

Time (hr)	(Pb^{+2} + Ni^{+2})				(Pb^{+2} + Cu^{+2})			
	Conc. of Pb^{+2} (mg/l)	Conc. of Ni^{+2} (mg/l)	R% (Pb^{+2})	R% (Ni^{+2})	Conc. of Pb^{+2} (mg/l)	Conc. of Cu^{+2} (mg/l)	R% (Pb^{+2})	R% (Cu^{+2})
0.25	0.522	1.36	98.956%	97.28%	0.15	6.17	99.7%	87.66%
1	0. 558	1.796	98.884%	96.408%	0.21	6.245	99.58%	87.51 %
1.5	0.781	2.186	98.438%	95.628%	0.23	6.552	99.54%	86.896%
2	0.736	2.326	98.528%	95.348%	0.26	7.452	99.48 %	85.096%

Time (hr)	(Cu^{+2} + Ni^{+2})			
	Conc. of Cu^{+2} (mg/l)	Conc. of Ni^{+2} (mg/l)	R% (Cu^{+2})	R% (Ni^{+2})
0.25	0.26	0.5	99.48 %	99 %
1	0. 277	0.9	99.446 %	98.2%
1.5	0.345	0.95	99.31 %	98.1%
2	0.366	1.05	99.268 %	97.9 %

Table (3): Feed Solute Concentration in Permeate and Membrane Rejection Percentage (*R %*) with the Time for Ternary Feed Solution

Time (hr)	Conc. of Pb^{+2} (mg/l)	Conc. of Cu^{+2} (mg/l)	Conc. of Ni^{+2} (mg/l)	(R%) (Pb)	(R%) (Cu)	(R%) (Ni)
0.25	1.128	7.137	1.665	97.744%	85.726%	96.67%
1	1.148	7.879	2.127	97.704%	84.242%	95.746%
1.5	1.767	7.979	2.198	96.466%	84.042%	95.604%
2	1.906	8.882	2.554	96.188%	82.236%	94.892%

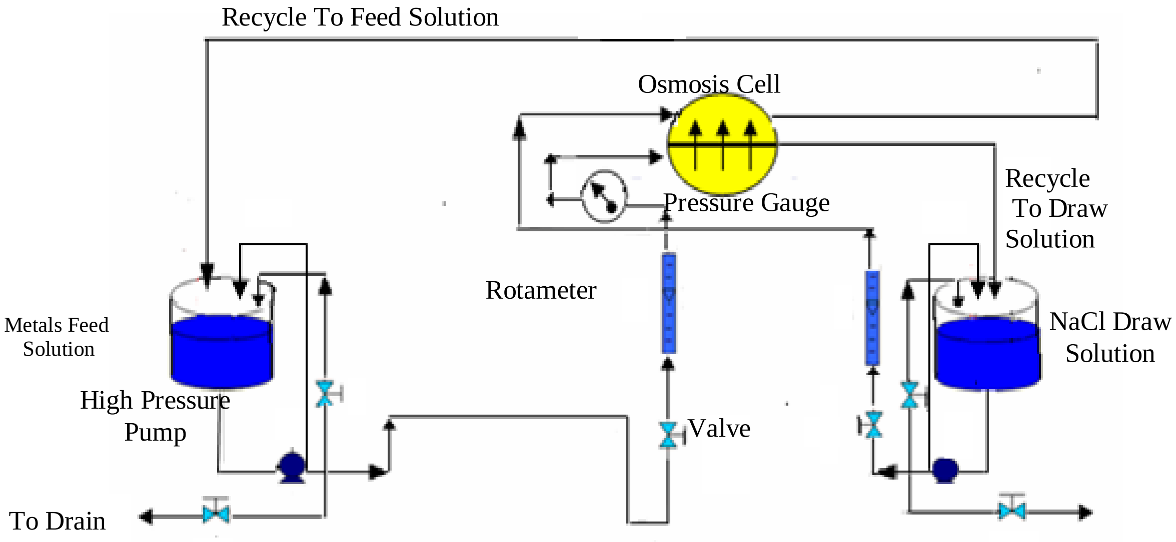

Figure (1): The schematic diagram of forward osmosis process.

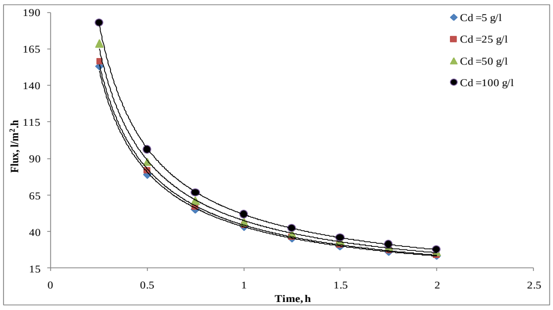

Figure 2. Water flux with time at different NaCl concentration (Pb(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2. bar).

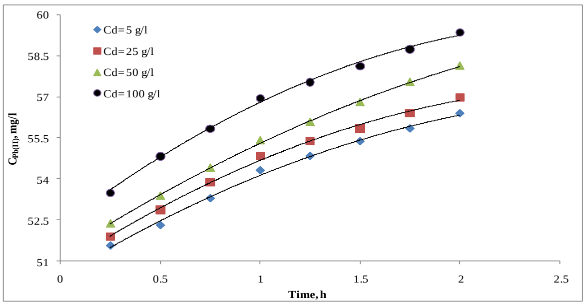

Figure 5. Feed solution outlet concentration (Pb(II)) with time at different NaCl concentration (Pb(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

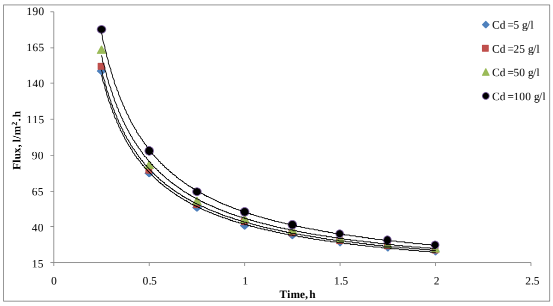

Figure 3. Water flux with time at different NaCl concentration (Cu(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

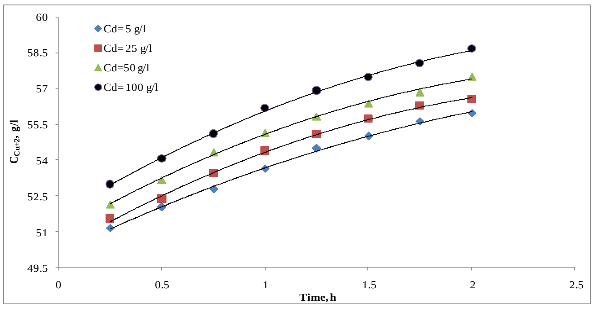

Figure 6. Feed solution outlet concentration (Cu(II)) with time at different NaCl concentration (Cu(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

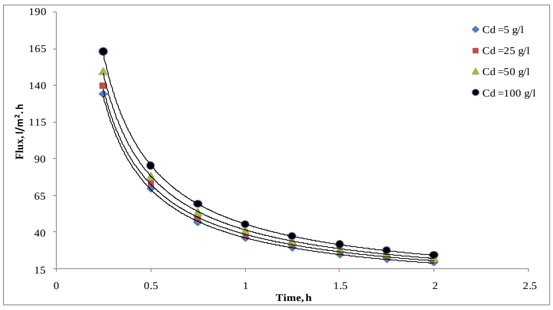

Figure 4. Water flux with time at different NaCl concentration (Ni(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

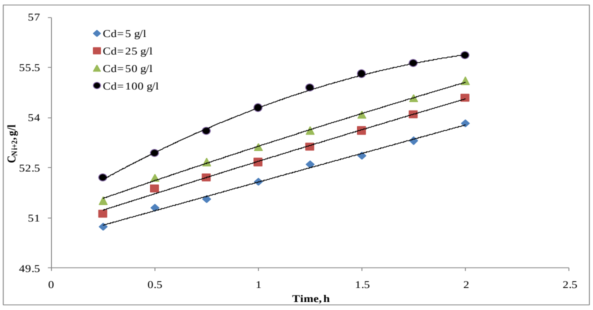

Figure 7. Feed solution outlet concentration (Ni(II)) with time at different NaCl concentration (Ni(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

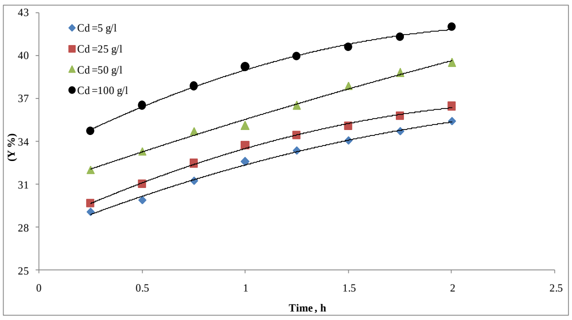

Figure 8. Recovery (Y%) with time for different NaCl concentration (Pb(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f =60 l/h, and p = 0.2 bar).

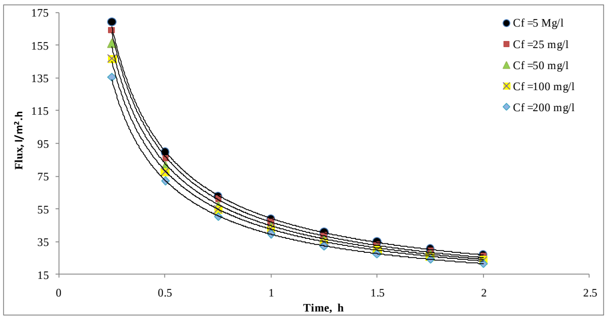

Figure 11. Water flux with time at different Pb(II) concentration (NaCl concentration = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f =60 l/h, and p = 0.2 bar).

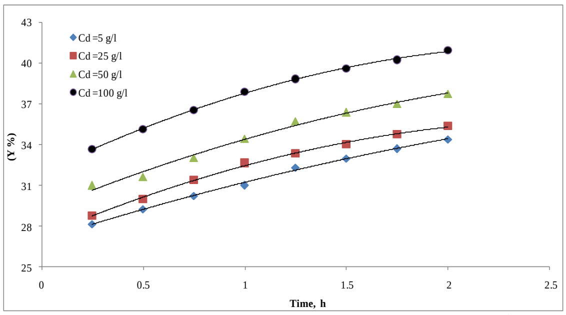

Figure 9. Recovery (Y%) with time for different NaCl concentration (Cu(II)concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

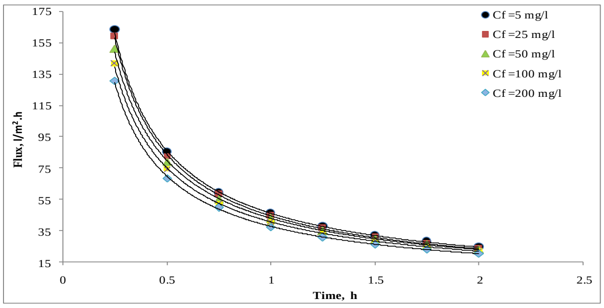

Figure 12. Water flux with time at different Cu(II)concentration (NaCl concentration = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

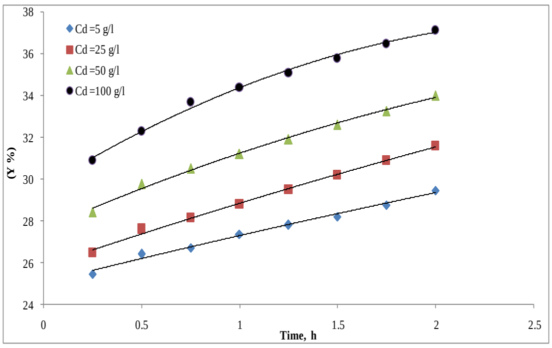

Figure 10. Recovery (Y%) with time for different NaCl concentration (Ni(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

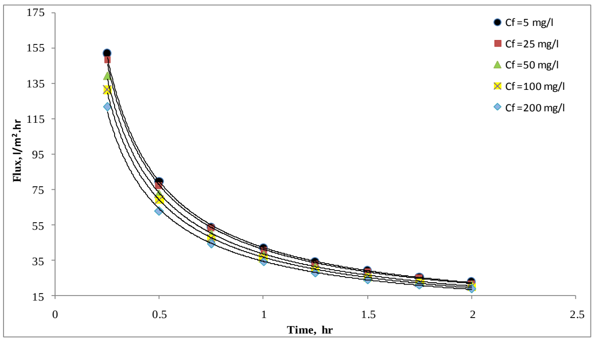

Figure 13. Water flux with time at different Ni(II) concentration (NaCl concentration = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f =60 l/h, and p = 0.2 bar).

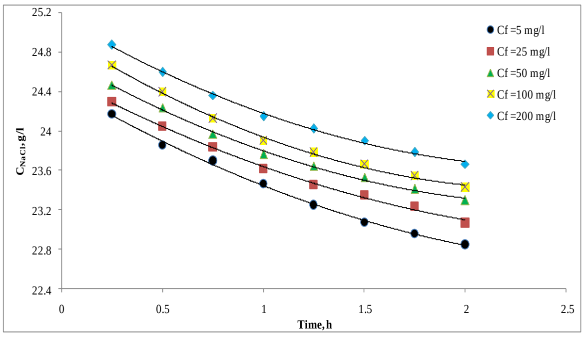

Figure 14. Draw solution outlet concentration (NaCl) with time at different Pb(II) concentration (NaCl concentration = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

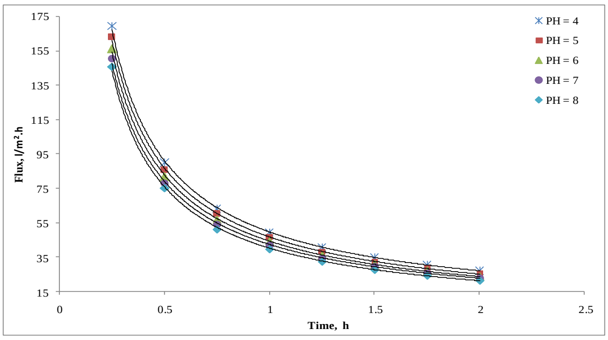

Figure 17. Water flux with time at different pH of feed solution (NaCl concentration = 25 g/l,Pb(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C , Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

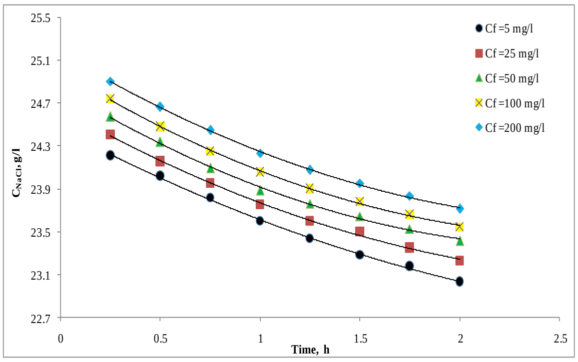

Figure 15. Draw solution outlet concentration (NaCl) with time at different Cu(II) concentration (NaCl concentration = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

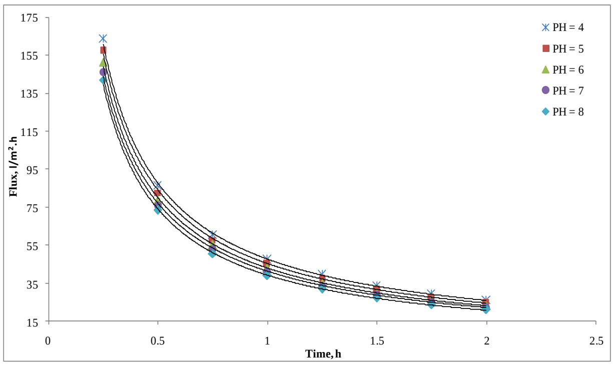

Figure 18. Water flux with time at different pH of feed solution (NaCl concentration = 25 g/l,Cu(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C , Q_d = 60 l/h, Q_f = 60 l/h and p = 0.2 bar).

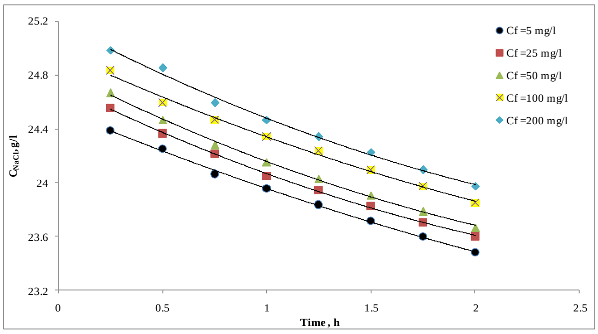

Figure 16. Draw solution outlet concentration (NaCl) with time at different Ni(II) concentration (NaCl concentration = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed = 6, Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

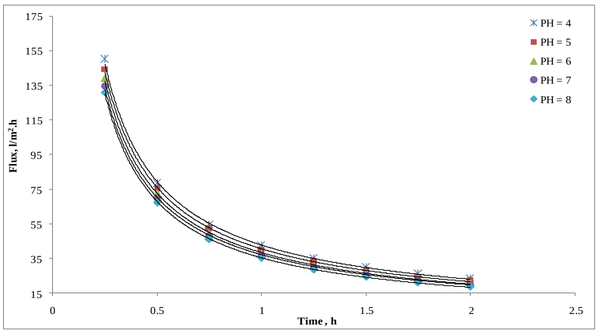

Figure 19. Water flux with time at different pH of feed solution (NaCl concentration = 25 g/l,Ni(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C , Q_d = 60 l/h, Q_f = 60 l/h, and p = 0.2 bar).

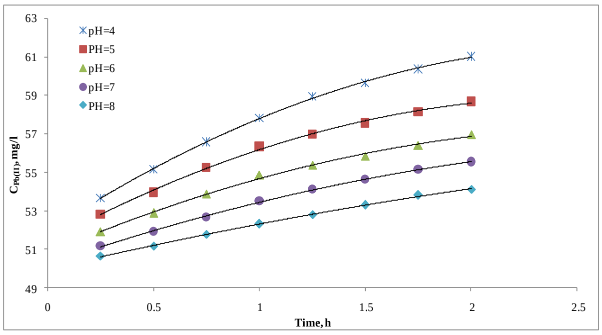

Figure 20. Feed solution outlet concentration (Pb(II)) with time at different pH of feed solution (NaCl concentration = 25 g/l,Pb(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C , Q_d = 60 l/h, Q_f= 60 l/h, and p = 0.2 bar).

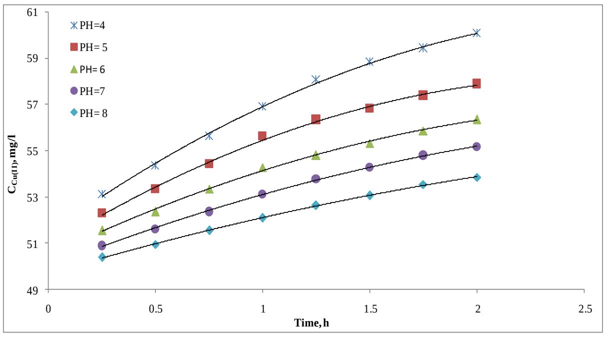

Figure 21. Feed solution outlet concentration (Cu(II)) with time at different pH of feed solution (NaCl concentration = 25 g/l, Cu(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C , Q_d= 60 l/h, Q_f= 60 l/h, and p = 0.2 bar).

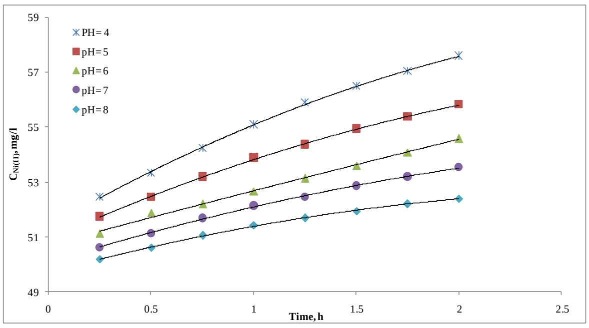

Figure 22. Feed solution outlet concentration (Ni(II)) with time at different pH of feed solution (NaCl concentration = 25 g/l, Ni(II) concentration = 50 mg/l, Temp. of FS & DS = 25 °C , Q_d= 60 l/h, Q_f= 60 l/h, and p = 0.2 bar).

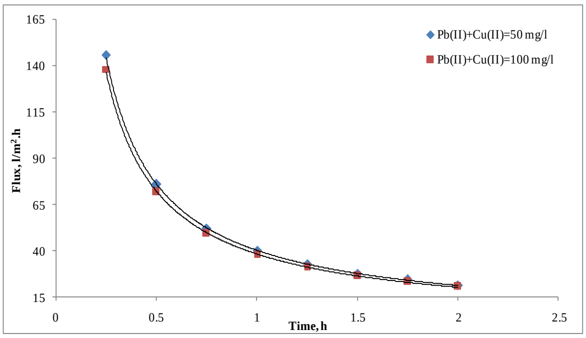

Figure 23. Water flux with time at different binary (Pb+2+Cu+2) concentration in feed solution (concentration NaCl = 25 g/l, Temp. of FS & DS = 25 °C. pH of feed=6, Qd = 60 l/hr, Qf =60 l/hr, and p = 0.2 bar).

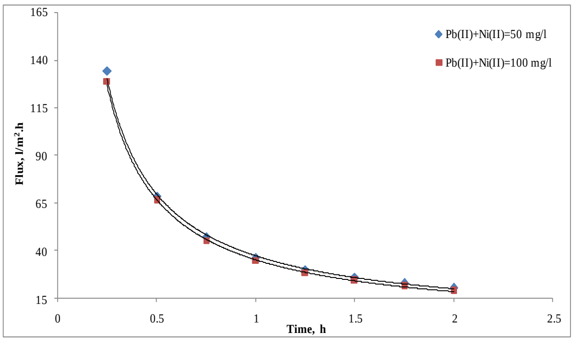

Figure 24. Water flux with time at different binary (Pb+2+Ni+2) concentration in feed solution (concentration NaCl = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed=6, Qd = 60 l/hr, Qf =60 l/hr, and p = 0.2 bar).

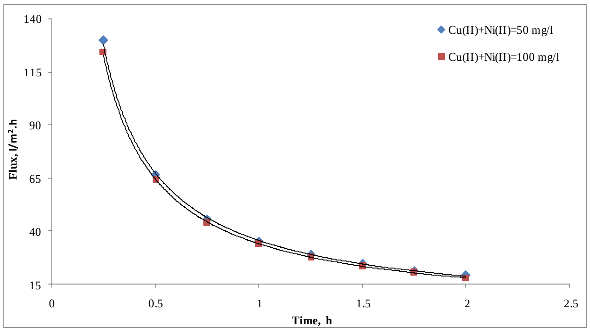

Figure 25. Water flux with time at different binary (Cu+2+Ni+2) concentration in feed solution (concentration NaCl = 25 g/l, Temp. of FS & DS = 25 °C, pH of feed=6, Qd = 60 l/hr, Qf =60 l/hr, and p = 0.2 bar).

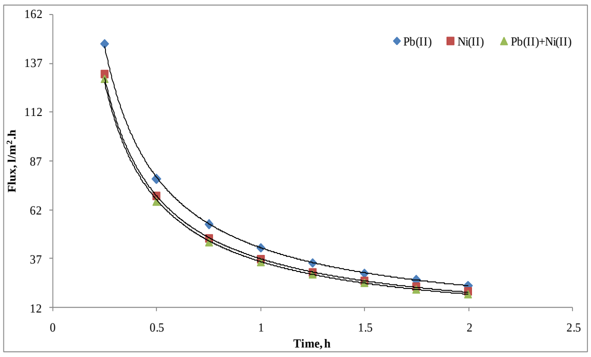

Figure 26. Water flux with time for different type of feed solution (concentration NaCl = 25 g/l, metal concentration = 100 mg/l, Temp. of FS & DS = 25 °C and pH of feed=6, Qd = 60 l/hr, Qf = 60 l/hr, and p = 0.2 bar).

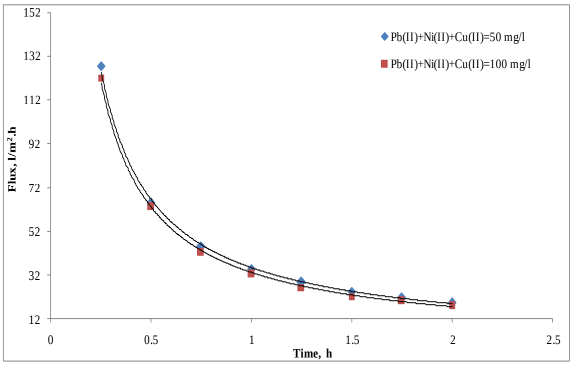

Figure 27. Water flux with time at different binary (Pb+2+Ni+2+Cu+2) concentration in feed solution (concentration NaCl = 25 g/l, Temp. of FS & DS = 25 oC, pH of feed=6, Qd = 60 l/hr, Qf =60 l/hr, and p = 0.2 bar).

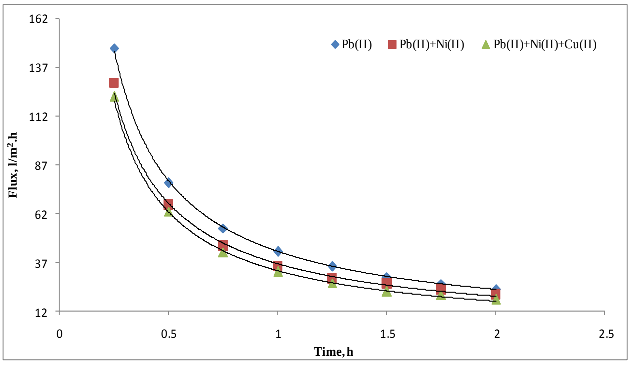

Figure 28. Water flux with time for different type of feed solution (concentration NaCl = 25 g/l, metal concentration = 100 mg/l, Temp. of FS & DS = 25 oC and pH of feed=6, Qd = 60 l/hr, Qf =60 l/hr, and p = 0.2 bar).

NOMENCLATURE

Symbol	Definition	Units
C_D	Concentration of Draw side	g/l
C_F	Concentration of Feed side	mg/l
C_P	Product Concentration	mg/l
I	Dissociation factor	*i*
Q_d	Draw Solution Flow Rate	l/h
Q_f	Feed Solution Flow Rate	l/h
J	Water Flux	$l/m^2.h$
Q	Flow Rate	l/h
R	Rejection Percentage	
R_g	Gas Constant	bar. l/gmol. k
T	Time	H
T	Temperature	°C
V_F	Volume of Water in Feed Vessel	L
V_P	Product Volume of Water	L
Y	Recovery Percentage	

Greek Symbols

Π	Osmotic Pressure	bar
Φ	Osmotic Coefficient	

Abbreviation

CP	Concentration Polarization
DI	Deionized water
DS	Draw Solution
FO	Forward Osmosis
FS	Feed Solution
RO	Reverse Osmosis
TFC	Thin Film Composite (TFC) membrane polyamide

ازالة ايونات الرصاص، النحاس، والنيكل من المياه الملوثة بعملية التناضح الأمامي

احمد عبد محمد [1]، احمد فائق العلوي [2]، تمارا كوثر حسين [3]
[1]، [2] استاذ مساعد، [1] قسم هندسة البيئة، [2] قسم هندسة الكيمياوية / كلية الهندسة – جامعة بغداد
[3] قسم هندسة البيئة، كلية الهندسة – جامعة المستنصرية

الخلاصة

في هذة الدراسة تم تطبيق عملية التناضح الأمامي (FO) لازالة ايونات المعادن(الرصاص , النحاس, والنيكل) من المياه الملوثة.غشاء البولي امايد (البوليمر مركب رقيق الغشاء(TFC))استعمل على شكل صفيحة مستوية لرفض المعادن الثقيلة عندما يقابل محلول التغذية اللقيم الجهة الفعالة للغشاء الناضح واستعمال تراكيز مختلفة من محلول كلوريد الصوديوم كمحلول سحب .العوامل التشغيلية التي تم دراستها كانت : تركيز محاليل السحب (5–100غرام / لتر), تركيز محاليل اللقيم (5–200 ملي غرام / لتر) , درجة حامضية محلول اللقيم (4 – 8), الضغط و درجة الحرارة ثابتين عند 0.2 بار و25 °م على التوالي. لقد وجد بأن معدل تدفق الماء يزداد بزيادة تركيز محلول السحب ويقل بزيادة تركيز محلول اللقيم و زيادة درجة حامضية محلول اللقيم. لعدة أنواع من المعادن الثقيلة المستخدمة كمحاليل اللقيم كان ترتيب معدل الانتقال هو $Pb^{+2} > Cu^{+2} > Ni^{+2}$. لمحلول اللقيم الثنائي والثلاثي كان معدل انتقال الماء يقل مع الزمن وزيادة تركيز محلول اللقيم نتيجة إلى نقصان القوة الدافعة للانتقال. التناضح الأمامي (FO) يستخدم لاسترجاع المياه من مياه الصرف الصحي الملوثة بالمعادن الثقيلة مع كفاءة رفض اكبر من 99%, 97% , و87% للرصاص , النحاس, والنيكل على التوالي.