ISSN: 0976-3104
REGULAR ISSUE
Din et al.

RESEARCH ARTICLE OPEN ACCESS

PERFORMANCE OF LOW PRESSURE REVERSE OSMOSIS MEMBRANE TREATING SYNTHETIC NATURAL ORGANIC MATTER (NOM) AND ENDOCRINE DISRUPTING CHEMICAL (EDC)

Mohd Fadhil Md Din[1], Rafidah Shahperi[1] and Shreeshivadasan Chelliapan[2*]

[1]*Institute of Environmental Water Resources and Management (IPASA), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, MALAYSIA*

[2]*UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia (International Campus), Jalan Semarak, 54100, Kuala Lumpur, MALAYSIA*

ABSTRACT

The current study describes the performance of low pressure reverse osmosis membrane (LPROM) treating synthetic wastewater containing dichlorodiphenyltrichloroethane, DDT (endocrine disrupting chemical, EDC) and glucose (natural organic matter, NOM) at various operating pressure and pH. The experimental results were compared to a modified design expert model using response surface method (RSM). Results showed up to 94.6% DDT and 85% glucose removal was achieved in the membrane system at an operating pressure and pH of 100 psi and 9, respectively, indicating efficient performance of the system. However, when the membrane system was operated at elevated pressure and low pH (120 psi and pH 5.5), the DDT and glucose removal efficiencies decreased to 91.2 and 75.5%, respectively, indicating operating pressure and pH affected the performance of the system. The design expert analysis for both DDT and glucose showed high removal efficiencies (93.67 and 81.70%) when the LPROM was operated at 114.14 psi, confirming that the LPROM is an excellent system for the treatment of EDC and NOM containing wastewater.

Received on: 10th-Sept-2011
Revised on: 2nd-Jan-2012
Accepted on: 9th-Feb-2012
Published on: 2nd-Mar-2012

KEY WORDS

Reverse osmosis (RO); low pressure reverse osmosis membrane (LPROM); endocrine disrupting chemical (EDC); natural organic matter (NOM); dichlorodiphenyltrichloroethane (DDT); glucose

***Corresponding author:** Email: shreeshivadasan@ic.utm.my; Tel: 006-03-26154581; Fax: 006-03-26934844

[I] INTRODUCTION

Membrane technology is considered as one of the most effective process for water and wastewater treatment. It is a compact system, economically feasible and has high pollutant removal efficiency. The technology has been proven to be effective and offers an alternative system where better effluent quality was produced in wastewater treatment plant [1, 2]. In general, the membrane process can be divided into four major classifications: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). In the past, pressure-driven membrane processes such as RO had gained special attention due to its effective removal of pollutants, especially those with low concentrations.

The wastewater treatment and reclamation by RO has developed tremendously. These include enhancement in salt removal capabilities, chemical stability and perhaps most importantly, pressure requirements [3]. RO is a process that reversing natural phenomenon of osmosis by applying pressure on the concentrated solution in contact with a semi-permeable membrane. This pressure-driven process rejects dissolved constituents that present in the feed water due to size and charge exclusion and physical chemical interactions between solute, solvent and membranes [4]. However, the use of RO is limited due to high operational cost especially when high pressure is applied. Therefore, low pressure reverse osmosis membrane (LPROM) has been introduced to water and wastewater industries in the past few years [5, 3, 6, 7].

Most of LPROM are multi-layer thin film composed of complex polymers. The active membrane surface layer normally consists of negatively charged sulphone or carboxyl group. This helps the membranes in improving of fouling resistance against hydrophobic colloids, proteins, oils and other organics. In order to increase water flux, a charged hydrophilic layer is attached to a hydrophobic UF support membrane. This makes the membrane favorable for the orientation of water dipoles. Flux is inversely proportional to the membrane thickness. Generally, LPROM contains corrugated skin surface that can improve flux significantly. It produces specific flux more than 60 $L/m^2.h$ MPa (flux per membrane area and per net driving pressure) at low operating pressure. This flux rate is about double the flux of the previous generations of composite RO membrane.

www.iioab.org
THE IIOAB JOURNAL
www.iioab.webs.com
CHEMICAL BIOLOGY

www.iioab.org
THE IIOAB JOURNAL
www.iioab.webs.com
CHEMICAL BIOLOGY

LPROM has the advantage of removing organic and inorganic species as compared to the conventional RO membranes [8]. According to Hofman [6], LPROM showed high removal efficiency for organic micro pollutants and pesticides. Based on LPROM specifications, the energy capacity could be lower than the conventional RO which is about 30 – 40%. Moreover, LPROM is also used for direct treatment of surface water that contains dissolved salts and organic substances.

In general, EDC in wastewater effluent and surface water has raised substantial concern in the public and regulatory agencies. Therefore, there is a potential for LPROM system to be used as a treatment unit for EDC containing wastewater and could offer high treatment efficiency at low costs. As a result, the main aim of this research was to evaluate the DDT and glucose removal efficiency in a LPROM system that operates at various pressure and pH. In addition, the performance of the membrane system was compared to a modified model using design expert analysis to show whether differences occur between the experimental study and the predicted model.

[II] MATERIALS AND METHODS

2.1. Experimental setup and operation

The experimental design was performed using response surface method (RSM) where it uses mathematical and statistical techniques. A multi-layer thin-film of aromatic polyamide (ES20) membrane was used for the LPROM study using a cross flow module (C10-T) [Figure–1].These membrane consist of carboxyl and amine with effective surface area of 60 cm^2. The DDT and glucose concentrations were measured using a UV-spectrophotometer.The experimental study was performed by varying pH (2 – 9) and operating pressure (80 – 120 psi) with Design Expert Version 6.0.4 software [Table-1].

The preparation of medium and stock solution was performed using standard chemical measurement. Initially, a stock solution of 10 mg/L^{-1} of synthetic wastewater containing DDT or glucose was prepared. The stock solution was used to prepare the required concentration of sample solutions. Later, the sample solutions were mixed with Hydrochloric Acid (HCl) or Sodium Hydroxide (NaOH) for pH adjustment. The volume of stock solution required to achieve the desired concentration was determined by Molarity (M) balanced equation. Both samples (DDT or glucose) and hydrochloric acid (HCl) or Sodium Hydroxide (NaOH) were also prepared using the same procedures and formula.

2.2. Data analysis

The experimental data obtained from this study was calculated using the following formula:

i. Flux rate

$$F = \frac{\text{Average permeate}}{A \times t} \quad \text{… (Eq. 1)}$$

Where;
F = permeate flux ($L/m^2.h$)
A = effective area of membrane (60 cm^2)
t = internal time when each permeate is collected (0.5 hours)

ii. Removal efficiency [Eq. 2]

$$R = \frac{C_f - C_p}{C_f} \times 100\% \quad \text{…. (Eq. 2)}$$

Where;
Cf = feed concentration (mg/L)
Cp = permeate concentration (mg/L)

iii. Recovery rate (Eq. 3)

$$\text{Recovery Rate (\%)} = \frac{Q_p}{} \times 100\% \quad \text{….(Eq. 3)}$$

Where;
Qp = permeate flow rate (ml/min)
Qf = feed flow rate (ml/min)

The feed flow rate can be determined using mass balance equation:

$$Q_f = Q_p + Q_c \quad \text{….(Eq. 4)}$$

Qc = flow rate of the concentration / retentate (L/min).

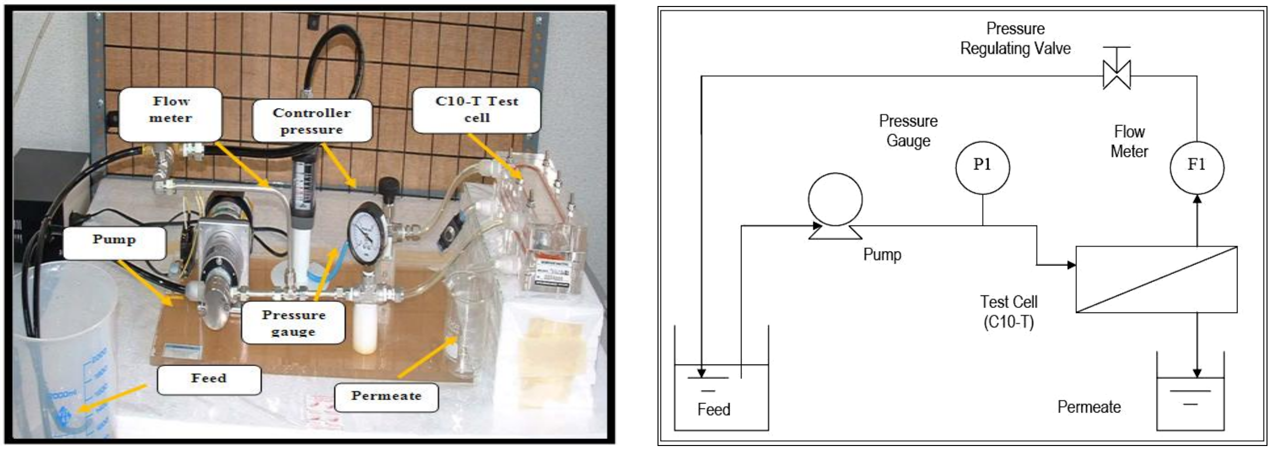

Fig: 1. LPROM set-up, Actual (left) and Schematic (right)

ISSN: 0976-3104

www.iioab.org
THE IIOAB JOURNAL

Table: 1. Operating characteristics during experimental study for DDT and glucose samples

Run Order	Operating Pressure (psi)	pH
1	114.14	3.03
2	100.00	5.50
3	80.00	5.50
4	100.00	9.00
5	120.00	5.50
6	100.00	2.00
7	85.86	3.03
8	114.14	7.97
9	85.86	7.97

[III] RESULTS AND DISCUSSION

3.1. DDT removal

Table-2 illustrates the DDT removal efficiency in the LPROM system treating synthetic wastewater at various operating pressure (80 - 120psi) and pH (2 - 9). The results showed that an average removal efficiency of 89.74% was achieved in the membrane system, indicating efficient performance of the system. The highest DDT removal efficiency (94.6%) was achieved at an operating pressure of 100 psi (pH 9, run order 3, **Table-2).** During this period, the flux rate was 32.67 L/m^2.h, however, when the membrane system was operated at high pressure (120 psi, pH 5.5, run order 6), the DDT removal efficiency decreased slightly to 91.2 %, indicating operating pressure effected the DDT removal efficiency and the flux rate (increased to 41 L/m^2.h, **Table 1**). One important observation during the study was the effect of pH on the treatment efficiency, where high removal efficiency (above 90%) was noted at elevated pH levels (e.g. pH 9) at operating pressure of 100 psi, except at pH 5.5, when the membrane system was operated at 120 psi. Since factors such as pH and operating pressure could affect the removal efficiencies of the LPROM system, it is important to control the flux rate for continuous operation and consistent removal of the micro pollutant. In general, the selected operational parameters in the current study **[Table-2]** had contributed to high DDT removal efficiencies compared to other parameters such as temperature and loading rate.

The design expert is a useful tool to perform statistical analysis, especially for the factorial design during the preliminary study of the LPROM. It should be mentioned here that the modified experiment on the selected operational parameters was previously studied by Hamdzah [9]. **Figure– 2** shows the surface response plots based on the modified model and it can be observed that the flux rate increased from 15.31 to 37.15 L/m^2.h when the pressure was gradually increased (85.86 to 114.14 psi). Additionally, the effect of controlled parameters on DDT removal efficiency was also investigated by using RSM **[Figure–3]** and showed high removal efficiencies (85.80 - 93.67%) when the LPROM was operated at 85.86 - 114.14 psi, confirming that the LPROM indeed an excellent system for the treatment of EDC containing wastewater. One possible reason for the increased removal efficiency is because of the decrease in the average pore size on membrane surface and increase in the preferential sorption of pure water at elevated pressure. Consequently, the sample molecules would be more difficult to permeate through the membrane at high operating pressure.

Table: 2. Operational parameters and DDT removal efficiency

Run Code	pH	Operating Pressure (psi)	Flux (L/m^2.h)	Removal / Rejection (%)	Final Concentration (mg/L)
1	5.50	80.00	10.00	89.1	1.09
2	7.97	85.86	12.67	92.5	0.75
3	9.00	100.00	32.67	94.6	0.54
4	5.50	100.00	26.00	89.7	1.03
5	5.50	100.00	26.00	89.7	1.03
6	5.50	120.00	41.00	91.2	0.88
7	2.00	100.00	30.67	84.2	1.58
8	5.50	100.00	26.00	89.7	1.03
9	7.97	114.14	34.67	93.2	0.68
10	5.50	100.00	26.00	89.7	1.03
11	5.50	100.00	26.00	89.7	1.03
12	3.03	114.14	35.00	87.0	1.30
13	3.03	85.86	14.33	86.3	1.37

www.iioab.webs.com

www.iioab.org
THE IIOAB JOURNAL
www.iioab.webs.com

It can be concluded that the DDT removal efficiency was effected by the different operating pressure and pH in the membrane system. Previous study using membrane treatment systems have shown that the operating pressure effected the permeate flux [10, 11, 12, 13]. For example, Ozaki [11] demonstrated that organic compound removal was effected by pH and the molecular weight in a LPROM system. They found an increase in organic compound removal rate at higher molecular weight. In addition, the current study had demonstrated that the LPROM under higher operating pressure encourages high feed flow across the membrane which produces high permeate. In another word, pressure is applied to force the concentrated feed solution to flow across the membrane to produce less concentrated permeate. According to Ujang and Anderson [11], permeate flux was high when pressure was increased in a LPROM system treating synthetic wastewater containing heavy metals. Similar trend was also observed in the current study where high permeate flux was detected at elevated pressure and an increase in DDT removal efficiency.

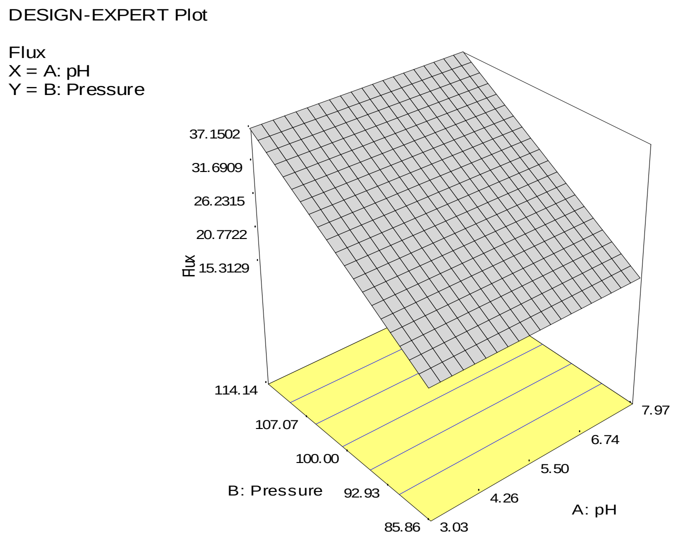

Fig: 2. Surface response plot (relationship between operating pressure, pH and permeate flux for DDT)

3.2. Glucose removal

Glucose is a synthetic organic substance with high carbohydrate compounds which may reduce the effectiveness of LPROM, particularly during the formation of humic acid. Therefore, the possible of glucose removal at a short period is necessary and in the present study, the average glucose removal efficiency was 71.08 % **[Table-3].** The highest removal efficiency (85%) was observed at an operating pressure and pH of 100 psi and 9.0, respectively [run code order 7, **Table-3**]. The fluctuations in removal efficiency (55.5 – 85%) were mainly attributed to the different operating pressure and pH. On the other hand, the flux range was 3.07 - 16.67 L/m^2.h and the highest flux was achieved at 120 psi and at pH 5.5 (run code order 9); indicating operating pressure affected the flux rate. Similar to the DDT removal, the glucose removal efficiency was dependent on the pH, where high removal efficiency was observed at elevated pH levels, demonstrating the LPROM system performed well at alkaline conditions. In the following section, several data was presented in a graphical manner to show the flux pattern and glucose removal.

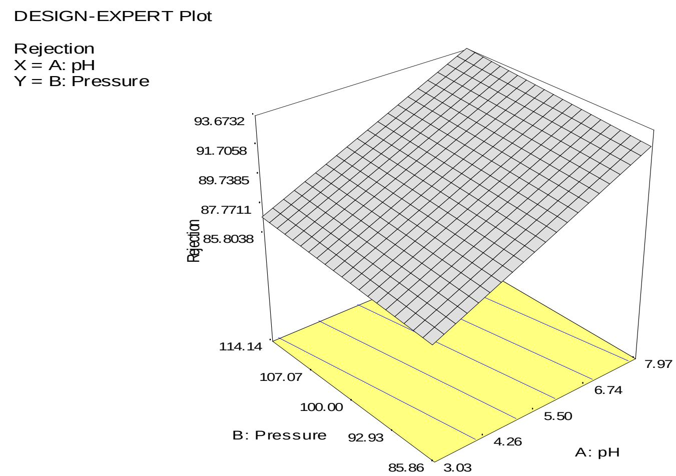

Fig: 3. Surface response plot for the effect of controlled parameters on DDT removal efficiency (relationship between operating pressure, pH and DDT removal efficiency)

3.2.1 Design expert analysis for glucose

Figure–4 shows the surface response and contour plots based on the modified model and shows an increase in flux rate (3.83 to 12.86 L/m^2.h) when pressure was increased (85.86 to 114.14 psi) gradually in the LPROM system. The effect of controlled parameters on the percentage of glucose removal was also investigated by RSM and the results were illustrated in **Figure–5**. The glocose removal efficiency was 59.17 - 81.70% when pressure was increased, a trend similar to the DDT removal in the modified model. The results of the modified model agrees with the actual experimental study where high removal efficiency was noted at elevated pressure.

Table: 3. Operational parameter and glucose removal efficiency

Run Code	pH	Operating Pressure (psi)	Flux (L/m^2.h)	Removal (%)	Final Concentration (mg/L)
1	5.50	100.00	6.50	71.5	2.85
2	7.97	114.14	11.67	84.2	1.58
3	5.50	100.00	6.50	71.5	2.85
4	2.00	100.00	6.33	55.5	4.45
5	7.97	85.86	4.00	77.2	2.28
6	5.50	80.00	3.07	67.0	3.30
7	9.00	100.00	7.67	85.0	1.50
8	3.03	85.86	4.33	60.0	4.00
9	5.50	120.00	16.67	75.5	2.45
10	3.03	114.14	10.67	62.2	3.78
11	5.50	100.00	6.50	71.5	2.85
12	5.50	100.00	6.50	71.5	2.85
13	5.50	100.00	6.50	71.5	2.85

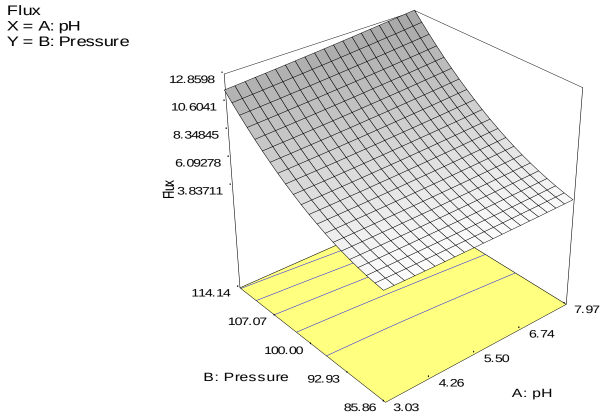

Fig: 4. Response surface plot (relationship between operating pressure, pH and permeate flux for Glucose)

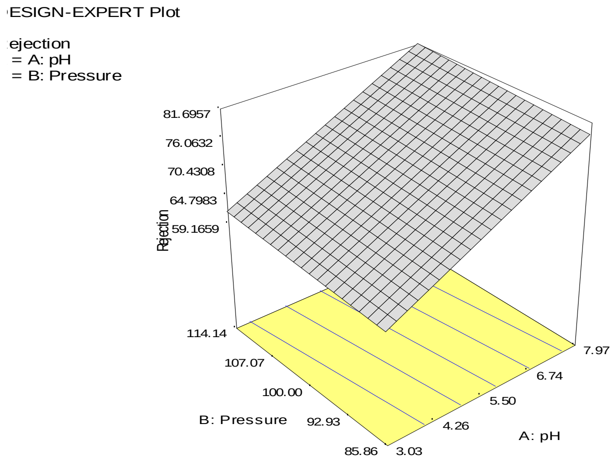

Fig: 5. Response surface plotting for the effect of controlled parameters on glucose removal efficiency

[V] CONCLUSION

The LPROM system is an appropriate option for the treatment of EDC and NOM containing wastewater and could offer high removal efficiency. Up to 94.6% DDT removal was achieved in the membrane system with effluent having a DDT value of 0.54 mg/L^{-1}. As for glucose, a typical removal efficiency of 85.0% was measured with effluent having a value of 1.50 mg/L^{-1}. The flux rate increased when the LPROM system was operated at elevated pressure, and had affected the removal efficiency of micro pollutant. The two parameters that most affected the performance of the membrane system were pH and operating pressure. In general, since the membrane system is considered as a low pressure system with high removal efficiency, it is paramount important to optimize the pH in the treatment process. Results showed that high removal efficiency was achieved at elevated levels of pH (e.g. at pH 9). In addition, the design expert analysis for both DDT and glucose using RSM have shown an increase in flux when pressure was increased gradually in the LPROM system.

FINANCIAL DISCLOSURE

This research was funded by Universiti Teknologi Malaysia under the postgraduate research scheme.

www.iioab.org
THE IIOAB JOURNAL
www.iioab.webs.com
CHEMICAL BIOLOGY

THE IIOAB JOURNAL
ISSN: 0976-3104

www.iioab.org
THE IIOAB JOURNAL
www.iioab.webs.com

CONFLICT OF INTERESTS

Authors declare no conflict of interests.

ACKNOWLEDGEMENT

The authors thank Faculty of Civil Engineering, Universiti Teknologi Malaysia and Ministry of Higher Education, Malaysia for their support during the project.

REFERENCES

[1] Wen X, Ding H, Huang X, et al. [2004] Treatment of Hospital Wastewater using a Submerged Membrane Bioreactor. *Process Biochemistry* 39: 1427–1431.
[2] Pauwels B, Fru Ngwa F, Deconinck S, et al. [2006] Effluent Quality of a Conventional Activated Sludge and a Membrane Bioreactor System Treating Hospital Wastewater. *Environmental Technology* 27: 395–402.
[3] Filteau G, Moss P. [1997] Ultra-low pressure RO Membranes: An Analysis of Performance and Cost. *Desalination* 113: 147–152.
[4] Malaeb L, Ayoub GM. [2010] Reverse osmosis technology for water treatment. State of the art review. *Desalination.* (Unpublished).
[5] Ujang Z, Anderson GK. [2001] Effect of the Operating Parameters on the Separation of Metal Chelates using Low Pressure Reverse Osmosis Membrane (LPROM). *Water Science & Technology* 41: 135–142.
[6] Hofman JA, Folmer MHEF, Kruithof JC. [1997] Removal of Pesticides and other Micropollutants with Cellulose-actate, Polymide and Ultra-low Pressure Reverse Osmosis Membranes. *Desalination* 113: 209–214.
[7] Ozaki H, Sharma K, Saktaywin W. [2001] Performance of an Ultra Low Pressure Reverse Osmosis Membrane (ULPROM) for Separating Heavy Metals: Effects of Interference Parameters. *Desalination* 144: 287–294.
[8] Minett S. [2003] Low Pressure, Reverse Osmosis Membrane for Drinking Water Supplies. *Membrane Technology* 73: 6.
[9] Hamdzah M. [2007]. Low pressure reverse osmosis membrane for rejection of heavy metals. Masters Thesis. Universiti Teknologi Malaysia, Malaysia
[10] Ujang Z, Anderson GK. [1998] Performance of Low Pressure Reverse Osmosis Membrane (LPROM) for Separating Mono- and Divalent Ions. *Water Science & Technology* 38: 521–528.
[11] Ozaki H, Li H. [2002] Rejection of Organic Compounds by Ultra-low Pressure Reverse Osmosis Membrane. *Water Research* 36: 123–130.
[12] Wu M, Sun DD, Tay JH. [2004] Effect of Operating Variables on Rejection of Indium using Nanofiltration Membranes. *Journal of Membrane Science* 240: 105–111.
[13] Ku Y, Chen SW, Wang, WY. [2004] Effect of Solution Composition on the Removal of Cooper Ions by Nanofiltration. *Separation and Purification Technology* 43: 135–142.