Saturation Time Characteristics of RO Membrane Skid to Clean Water Supply with Pressure Stage in Rejection

Muhammad Zakwan¹, Anton Prayoga¹ and Setijo Bismo¹,²

¹Department of Chemical Engineering, Faculty of Engineering, University of Indonesia, Depok, West Java, 16424, Indonesia.
Email: *muhammad.zakwan@ui.ac.id*
Corresponding author: ²setijo.bismo@ui.ac.id

Abstract. Reverse osmosis (RO) is one major water treatment process used to filter out the water pollution due to the Tsunami disaster in Pandeglang. This technology is applied where highly purified water is essential, including sea/groundwater desalination, boiler feed water filtering, product rinsing, laboratory testing, and biotechnology. However, RO requires advanced research to ascertain the method and optimum pressure of the multi-pass system needed to produce clean water through a membrane with a long saturation time. Therefore, this study employs RO multi-pass by varying pressure 6-3, 6-4, and 7-4 on the first and second stage to observe the effects of decreasing flux and TDS enhancement for 72 hours in Tanjung Lame village. The results showed more performance in producing potable water at pressure $P_1 = 6$ bar/$P_2 = 3$ bar compared to $P_1 = 6$/$P_2 = 3$, and $P_1 = 7$/$P_2 = 4$. Moreover, the total dissolved solids (TDS) known to satisfy clean water provision was estimated at 20 ppm, after the permeate in the first stage is used as feedstock in the second. Furthermore, applying $P_1 = 6$ bar and $P_2 = 3$ bar for the first and second stage produced the membrane saturation time in hours ranging between 72-80 and 72-131, respectively.

Keywords: Saturation time; RO multi-pass; Clean water

1. Introduction

Water sources containing high salinity are not fit for consumption, particularly for drinking. This is one of the major causes of clean water scarcity, recognized as a continuous global challenge, especially the residential population [2]. A typical instance shows Indonesia’s sub-districts, Pandeglang, where the locals experience difficulty accessing potable water.

Reverse Osmosis (RO) is a modern technology used to produce clean water in areas facing water scarcity [5]. This application is fast gaining worldwide acceptance in both water treatment and desalination processes; hence supplying clean water and purifying water from bacteria is effective [8]. However, one of the disturbing challenges in using membrane is devising ways to prolong the lifespan. Membrane fouling is the main factor caused by pore-clogging or adsorption of solutes on the surface and also shows adverse effects on the lifetime [6,7]. Few factors are known to affect membrane fouling, including pressure, recovery, and salt passage. Scaling of the RO membrane results from precipitation of saturated salts onto the surface and is triggered by fouling. However, molecules in solutes tend to reject or accumulate with the pore-clogging results, which also triggers concentration polarization phenomena [9]. This phenomenon increases as the recovery rate progresses, causing the
total dissolved solids (TDS) in the permeate to increase significantly [10]. Concentration polarization is a reason for flux decline at the initial separation process, which is occurred in conjunction with irreversible fouling of gel/cake layer formation. Concentration polarization occurs in any pressure-driven membrane separation process [4]. In other words, concentration polarization describes an increase concentration at the membrane wall due to the rejection of ionic through the membrane by the convective process.

Furthermore, the pressure is also a recognized factor affecting fouling. The specific pressure needed to push water through the membrane is called transmembrane pressure. Therefore, flux increases as the transmembrane pressure also scale [9]. This, however, occurs on feed with low salinity or low TDS. The equation for the transmembrane pressure in RO is specified below.

\[
\text{pressure drop (dp) } = P_f - P_c \tag{1}
\]

\[
\text{transmembrane pressure (TMP) } = \frac{(P_f + P_c)}{2} - P_p \tag{2}
\]

Where:
- \(P_f\) = feed pressure
- \(P_c\) = concentrate/drain pressure
- \(P_p\) = Permeate pressure

The other factors contributing to membrane fouling are salt passage and recovery. As mentioned earlier, increased recovery tends to accelerate the fouling process. This also applies to the salt passage, where a large amount of salt is passed through the membrane. Based on a technical note, the membrane is confirmed clean as flux reduction achieves 10-15% from the initial value, while salt passage records between 5-10% [6].

Several strategies are adopted to extend membrane lifespan. An operating membrane in a cross-flow system demonstrates improved performance in prolonging the lifetime compared to an operating membrane in a dead-end system, where the flux in a cross-flow system wipes out all molecules or ions clogging the pores of the layer [9]. In addition, the use of multi-pass RO configuration also increases the lifetime, where the product in the first membrane is applied as feedstock for the second. Instead of using a multi-pass configuration, appropriate pre-treatment is potentially employed to alleviate the fouling [1]. Conventional pre-treatment has been widely applied to pretreat seawater and brackish water RO, including acid addition, coagulation, media filtration, and up to cartridge filtration. However, new trends in pre-treatment such as MF, UF, and NF, is rapidly gaining preference [3]. Based on Jia Xu (2006), UF is used as pre-treatment in the UF-RO system showed effective performance [11].

Therefore, this paper investigates the membrane saturation time in supplying clean water on low pressure using a multi-pass configuration known to affect the membrane lifespan. The membranes are used in this research is a household membrane. In the first and second RO stages, the optimum pressure is obtained by correlating pressure, flux, and TDS. Under these circumstances, the membrane lifespan is conveniently calculated.

2. Materials and method

2.1. Material and Tools

The experiment used brackish water with a constant TDS 2980 ppm from a well in Tanjung lame village and kept in the regular tank, which dimension about 2,500L. The tank was placed 2-meters height above the RO instrumentation. All membranes modules used for the experiment are RO TFC ultra-low pressure with type ULP-3013-400 for the first stage and WW-2012-100 for the second stage. That is why this research used pressure lower than 10 bars. The pump used to press the water through the membrane in both stages is a 36V diaphragm pump. All pumps are controlled using a pressure
2.2. The installation and procedure

The Design of RO water treatment used a two-stage system, in which the product in the first stage is used for the second stage, and the instrumentation presented in Figure 1. In this design, there are three UF membrane-type hollow-fiber with a cross-flow system used as pre-treatment before water from the tank flow through the first stage of the RO membrane. Between UF and the first stage of RO is connected to a low-pressure switch to control the pump in the first stage. It will turn off the pump for pressuring the water through the first stage membrane when the stream has pressure lower than 0.482 bar (7 psi). In the first stage, there are three RO membranes connected to a low-pressure switch. This low-pressure switch turned off the pump for pressuring the water through the second stage. The second membranes consist of six membranes, which are pumped by three pumps. Each pump pushed the water through two RO membranes in the second stage. The second stage stream is connected to a rotameter to measure the product’s flow rate and then be collected in a stainless-steel tank. Further, the rejection stream of all RO stage is connected to the pressure gauge and valve to control the membrane pressure.

The experiment is conducted in the two-step. The first step is employed three attempts, which was conduct for 4 hours of each attempt. The pressure stages used for three attempts, respectively, are 6-3, 6-4, 7-4 bar. The second step was conducted 72 hours using the best pressure-stage in the first step. During 72 hours, the flux decrease and TDS increase were observed to analyze. All attempts used the same membrane, but all membranes were cleaned before each variable is done. The flow rate of feed is 4.9 liters/minute.

Figure 1. The schematic diagram of the experimental for producing clean water
3. Result and discussion

3.1. Compared the use of pressure in decreased flux and increased TDS

Table 1 shows the data generated during this research. The effects of decreasing flux and increasing TDS are evaluated at varied pressure $P_1 = 6$ bar and $P_2 = 3$ bar for first experiment, $P_1 = 6$ bar and $P_2 = 4$ bar for second experiment, and $P_1 = 7$ bar and $P_2 = 4$ bar for third experiment. Furthermore, the comparison between these pressures was conducted for 4 hours with a constant feed flux of 4.90 liters/minutes. The results showed sufficient operating conditions of the pressure. Below is Table 1 listing the pressure comparison with $Q$-feed as feed flux, $Q$-$P_1$ as products in the first stage, and $Q$-$P_2$ as second stage products.

| Time (Hour) | Pressure$_1$ | Pressure$_2$ | Q-Feed | $Q$-$P_1$ | $Q$-$P_2$ | TDS $P_1$ | TDS $P_2$ | Salt Rejection$_1$ | Salt Rejection$_2$ |
|-------------|---------------|---------------|---------|-----------|-----------|------------|------------|-------------------|-------------------|
| 2           | 6             | 3             | 4.90    | 1.50      | 1.15      | 116        | 16         | 96.11             | 99.46             |
| 4           | 6             | 3             | 4.90    | 1.50      | 1.15      | 115        | 15         | 96.14             | 99.50             |
| 2           | 6             | 4             | 4.90    | 1.35      | 1.30      | 118        | 59         | 96.04             | 98.02             |
| 4           | 6             | 4             | 4.90    | 1.35      | 1.30      | 119        | 60         | 96.01             | 97.99             |
| 2           | 7             | 4             | 4.90    | 1.20      | 1.05      | 142        | 74         | 95.23             | 97.52             |
| 4           | 7             | 4             | 4.90    | 1.07      | 1.04      | 159        | 138        | 94.66             | 95.37             |

$Q$-feed: Flux-in (Litres per minute (LPM))
$Q$-$P_1$: Flux permeate the first stage (LPM)
$Q$-$P_2$: Flux permeate the second stage (LPM)
$P_1$: Pressure in the first stage (bar)
$P_2$: Pressure in the second stage (bar)
TDS: Total Dissolved Solid (ppm)
Salts Rejection (%)

Based on Table 1, the use of varied pressure $P_1 = 6$ bar and $P_2 = 3$ bar, also $P_1 = 6$ bar and $P_2 = 4$ bar demonstrates low decreasing flux compared to $P_1 = 7$ bar and $P_2 = 4$ bar. In the first experiment, $P_1 = 6$ bar and $P_2 = 3$ bar reported a constant value of decreasing flux ($Q$-$P_1$). These values indicate the membrane performed more efficiently during the 4 hours of operation, particularly in rejecting salt. In other words, the constant flux ($Q$-$P_1$ and $Q$-$P_2$) is true because of the absence of fouling or inability of permeate flux to reflect membrane fouling. For the second experiment, the use of $P_1 = 6$ bar, lower product flux exists compared to the first. Based on the theory, this is caused by concentration polarization, which causes the flux decline during the initial period of the membrane separation process [4]. Concentration polarization increased the osmotic pressure at the membrane wall, which causes a reduction in the permeate flux. In other words, higher pressure occurred to get constant flux. However, the use of $P_2 = 4$ bar in the second stage decreases the salt rejection from 98.02% - 97.99%. The phenomenon indicates additional salt passes through the membrane and the polarization of concentration [6]. $P_2 = 4$ bar gives higher flux than $P_2 = 3$ bar, which gives higher power to push water for diffusion through the membrane. However, it increased the rate of concentration polarization, which increases the risk of fouling. $P_2 = 4$ bar also increases the solute breakthrough into the permeate stream. At pressure $P_1 = 7$ bar and $P_2 = 4$ bar, product flux acquired a lower value than the first and second experiments. This is caused by the polarization of concentration present in the third experiment and is greater among other experiments. The use of $P_1 = 7$ bar and $P_2 = 4$ bar demonstrated the highest TDS value. High-pressure forces the salt through the membrane resulting in the formation of gel, which clogs the wall and causes a lower water diffusion rate. Applying pressures, $P_1 = 7$ bar, and $P_2 = 4$ bar rapidly lower the flux. Based on the effects of flux decreasing and TDS increasing was evaluated by pressure variations, the optimum pressures with long membrane saturation time are estimated at $P_1 = 6$ bar and $P_2 = 3$ bar.
3.2. Estimated the saturation time of membrane using method decreased of flux and increased of TDS

This optimum pressure is then selected to evaluate the membrane saturation time. Figure 2 shows the effects of pressure on decreasing flux (Q) at 72 hours.

![Figure 2. The effect of pressure on flux decrease (a) P₁ = 6 bar (Q₁P₁) and (b) P₂ = 3 bar (Q₁P₂)](image)

Based on Figure 2.a, the flux declined from 1.5 - 1.3 liters/minute. Total decreasing flux was estimated at 0.2 liters/minute for 72 hours or at 13%. The decrease of flux is caused by the accumulation of salt that prevents water diffusion through the membrane. This is due to the accumulation of dissolved solids in the membrane. Figure 2.a shows the equation \( y = 1.4954e^{-0.002x} \), where e is the Euler number. Assumed the membrane is changed at a decreased flux of 15%, the membrane saturation time is then calculated using the above equation to obtain 80 hours at maximum. Therefore, based on decreasing flux, the membrane is expected to be changed at a time range of 72-80 hours.

Figure 2.b shows that a lower flux was produced in the second stage compared to the first. The second stage's flux is lower than the first stage due to the flux distribution into drainage flux and permeates flux. Figure 2.b at a range of 15-60 hours reveals constant flux. After 60 hours, the flux reduces to 1 liter/minute. This indicates the membrane saturation was significantly achieved. Total decreasing flux for 72 hours arrived at 13%. The graph in Figure 2.b was plotted from the equation \( y = 1.1147e^{-0.001x} \). Furthermore, the membrane is confirmed clean after the decreasing flux reaches 15%, and the membrane saturation time is calculated by using the equation above to generate a range of 72-131 hours. The second stage has the longest saturation time, which is compared to the first stage due to lower contaminant in the second stage. In addition, Figure 3.b shows lower TDS compared to Figure 3.a

Figure 3 shows the effects of pressure on increasing TDS with (a) P₁ = 6 bar and (b) P₂ = 3 bar. Besides, the TDS advanced from a range of 115-116 to 119 ppm due to salt accumulation instigated by pressure in the first stage. The first stage is shown by Figure 3.a, total increased TDS recorded 3% with the equation \( y = 115.05x e^{0.0004x} \) after 72 hours. Based on the technical note, the membrane is confirmed clean at 10% decreased salt rejection or increasing TDS of 413 ppm. Therefore, using the earlier equation, the membrane is possibly cleaned after 3,188 hours. Meanwhile, Figure 3.b shows the equation \( y = 15.29x e^{0.0037x} \), were assumed the membrane is cleaned at 10% decreased salt rejection, but with increasing TDS of 313 ppm. Therefore, the membrane saturation time is achieved at 816 hours.
Figure 3. The effect of Pressure on TDS increase (a) $P_1 = 6$ bar and (b) $P_2 = 3$ bar.

Compared to the calculations between both methods, the membrane saturation time using the decreased flux method delivered sufficient results compared to increasing TDS. Furthermore, the decreasing flux method is more representative of the existing theory, where membrane saturation time in the first stage appears faster than the second.

4. Summary

Based on results and discussion, this study showed the calculation saturation time of the membrane used the decreased flux method appears more representative compared to the increased TDS, with faster saturation time achieved in the first stage than in the second. However, the use of pressure with extensive membrane saturation time is ranked as $P_1 = 6$ bar and $P_2 = 3$ bar > $P_1 = 6$ bar and $P_2 = 4$ bar > $P_1 = 7$ bar and $P_2 = 4$ bar. Using $P_1 = 6$ bar and $P_2 = 3$ bar, the value at the first stage (ULP-3013-400) demonstrated a range from 72-80 hours, while the second (WW-2012-100) reported 72-131 hours.

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