Analyzing the Performance of Reverse Osmosis Membranes After the Cleaning Process: Case study Performed at PT. XYZ.

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Abstract

PT. XYZ uses a reverse osmosis (RO) system in demin water treatment. One of the weaknesses of the RO system is the formation of fouling on the membrane, which can reduce the performance of the membrane, so it is necessary to carry out an appropriate cleaning process to remove deposits on the surface of the membrane, restore the separation characteristics, and restore the normal capacity of the system. This research aims to examine the effect of cleaning on the performance of reverse osmosis membranes in the PT. XYZ with requirements for reverse osmosis membrane type FILMTEC BW30–400 IG. The research was conducted for 8 weeks by collecting data on the reverse osmosis control box and control room in the form of product flow rate, feed conductivity, and product conductivity. Based on the results of the study, it can be concluded that the effect of cleaning on membrane performance can only extend the life of the membrane and cannot meet the specifications for the working parameters of the reverse osmosis membrane, which can be seen in the salt rejection, salt passage, and flux values obtained in this study.

Keywords: Flux; Membrane; Reverse osmosis; Salt passage; Salt rejection

1. Introduction

One of the primary considerations is the presence of toxic substances or pollutants in the form of minerals in water. Mineral contaminants can lead to significant issues, such as corrosion, scale formation, and carryover. Typically, several methods are employed to generate demineralized water, such as distillation, reverse osmosis, and deionization [1–3]. PT. XYZ utilizes a reverse osmosis (RO) system for its function for demineralizing water in the treatment process. Mineral water is a vital necessity utilized in the production process at PT. XYZ. The primary weakness of the RO system is caused by the possibility of fouling on the membrane, which has the potential to decrease performance and create a risk to the quality of the membrane. Therefore, it is crucial to carry out a suitable cleaning procedure to eliminate contaminants on the membrane surface, reestablish separation properties, and reestablish the system's standard capacity [4, 5]. Frequently, in practical situations, the membrane cleaning procedure fails to produce significant enhancements in membrane performance. Effective cleaning should be adjusted to the specific type and composition of fouling that has accumulated on the RO membrane. Cleaning must also pay attention to operating conditions such as pH, temperature, time, and cleansing dose.[6, 7].

Several investigations regarding the regulation of membrane fouling have been carried out. Lorain et al. (2007) have devised a feed water pretreatment technique employing ultrafiltration and sand filters [8]. Kang and Cao (2012) produced an antifouling membrane by physically and chemically modifying the membrane [9]. The types of foulants that contaminate RO membranes in wastewater treatment plants are organic foulants, colloidal foulants, microbiological foulants/biofouling, and inorganic/scaling foulants. These four categories of foulants could exist as single or combinations[10]. Whereas various strategies have been made to handle fouling, there is no method that can control fouling perfectly.

Acids, bases, oxidants, biocides, surfactants, or chelating agents are common chemicals used in membrane washing to remove fouling that accumulates on the membrane surface or membrane pores, depending on the fouling type and composition. [11–13]. The membrane cleaning process has various advantages, including the capacity to reduce or remove pollutants that accumulate on the membrane surface or in the membrane pores, causing a decrease in flux, low water quality, insufficient energy consumption, and membrane degradation; repair or improve membrane performance, such as water permeability, salt rejection, and selectivity; extend membrane life and minimize the frequency of membrane replacement; and might reduce operational and maintenance costs of membrane systems[14]–[16]. PT. XYZ now employs citric acid as a membrane-cleaning agent. In light of this, further study was carried out regarding the effect of cleaning on membrane performance using citric acid. Some researches have found that strong acids and high acid concentrations can cause membrane breakdown since the RO membrane structure is sensitive to pH levels [17]. Therefore, it is crucial to determine the proper cleaning chemical according to the type of foulant and membrane [16]. Several factors are the foundation for this research, which attempts to establish the influence of cleaning on the performance of RO membranes at PT. XYZ. The performance parameters of RO A and B membranes can be determined using numerous parameters, including salt rejection, salt passage, and flux rate.

2. Method

This research is a sort of case study carried out to evaluate the performance of reverse osmosis (RO) A and B membranes on PT. XYZ clear water pumps before and after cleaning. RO A and B have identical specifications; however they differ in terms of their lifespan. Specifically, RO B has been in use for more than a year, while RO A has been in operation for a period of 6 months. The reason of utilizing these two ROs is to carry out significant production requirements. The investigation was carried out for 8 weeks by obtaining data from the RO control box and control room in the form of product flow rate, feed conductivity, and product conductivity. The water product produced relies on the performance of the RO membrane. The cleaning method employs acid on the reverse osmosis membranes A and B three times during a period of 2 weeks for 8 weeks, utilizing citric acid with concentration of 100 g/L at pH 4. Collecting information in the control room and reverse osmosis control box is carried out every day. The washing procedure is carried out by mixing citric acid and water in the mixing tank, then circulating for 2–3 hours and soaking for 5–6 hours. After that, clean is carried out to eliminate remaining compounds in the membrane. The type of RO membrane utilized in PT. XYZ clear water pumps, is the FILMTEC BW30-400 IG Type. FILMTEC BW30-400 IG membrane specifications have been shown in Table 1.
The performance of the FILMTEC BW30-400 IG-type RO membrane can be evaluated based on three parameters: salt rejection, salt passage, and flux.

a. Salt Rejection

Salt rejection refers to the proportion of minerals and salts that cannot penetrate a semipermeable membrane and are consequently discharged as waste. The salt rejection % can be determined using equation (1).

$$Salt\ rejection\ (\%) = \frac{(Cf-Cp)}{Cf} x\ 100\% \tag{1}$$

Cf represents the conductivity value of the feed (µS/cm), while Cp represents the conductivity value of the permeate (µS/cm).

b. *Salt Passage*

Salt passage represents the percentage of salt that can pass through the RO membrane. The percentage of salt passage can be determined using equation (2).

$$Salt\ Passage\ (\%) = \frac{Cp}{Cf} x\ 100\% \tag{2}$$

While Cf is the feed conductivity value (µS/cm), and Cp is the permeate conductivity value (µS/cm).

c. Flux

Flux is an indicator of the rate of flow of a species across a membrane[18]. The water flux across the reverse osmosis membrane is proportional to the total pressure driving force provided to the water. The chemical and physical features of the membrane, such as surface charge and pore size, affect its ability to facilitate preferential transport of water over salt ions. Flux can be estimated using the equation (3).

$$J = \frac{Qp}{A} \tag{3}$$

With J is the flux rate ($m^3/m^2.h$), Qp is the flow rate of product water (permeate) (m^3/h), and A is the membrane surface area (m^2).

Table 1. FILMTEC BW30-400 IG Mebrane Spesifications [19].

Parameter	
Membran Type	*Polyamide Thin-Film Composite*
Maximum Operating Temperature	113°F (45°C)
Maximum Operating Pressure	600 psig (41 bar)
Maximum Pressure Drop	15 psig (1.0 bar)
pH Range, Continouos Operation	2-11
Maximum Feed Flow	70 gpm (15.9 m^3/hr)
Maximum Feed Silt Density Index	SDI 5
Free Chlorine Tolerance	< 0.1 ppm
Minimum Salt Rejection	99.0%
Stabilized Salt Rejection	99.5%
Permeate flow rate	10.500 gpd (40 m^3/d)

3. Results and Discussion

Water is a primary constituent employed in the production process of PT. XYZ. Domestic water gets initial treatment to become demineralized water, which is subsequently utilized for a range of production requirements including boiler feedwater, urea mixing ingredients, and other requirements. PT. XYZ use Brackish Water Reverse Osmosis (BWRO) technology to convert brackish water into demineralized water through the process of desalination. The cleaning evaluation outcomes of RO A and B membranes can be observed in Figure 1 and 2.

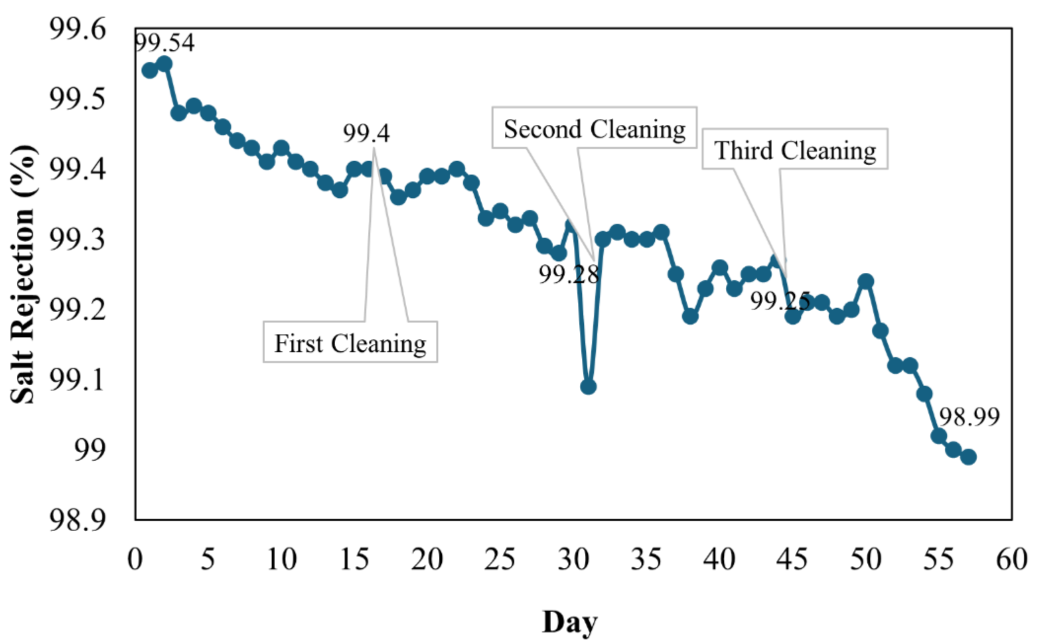

Figure 1. Salt Rejection at RO A Membrane

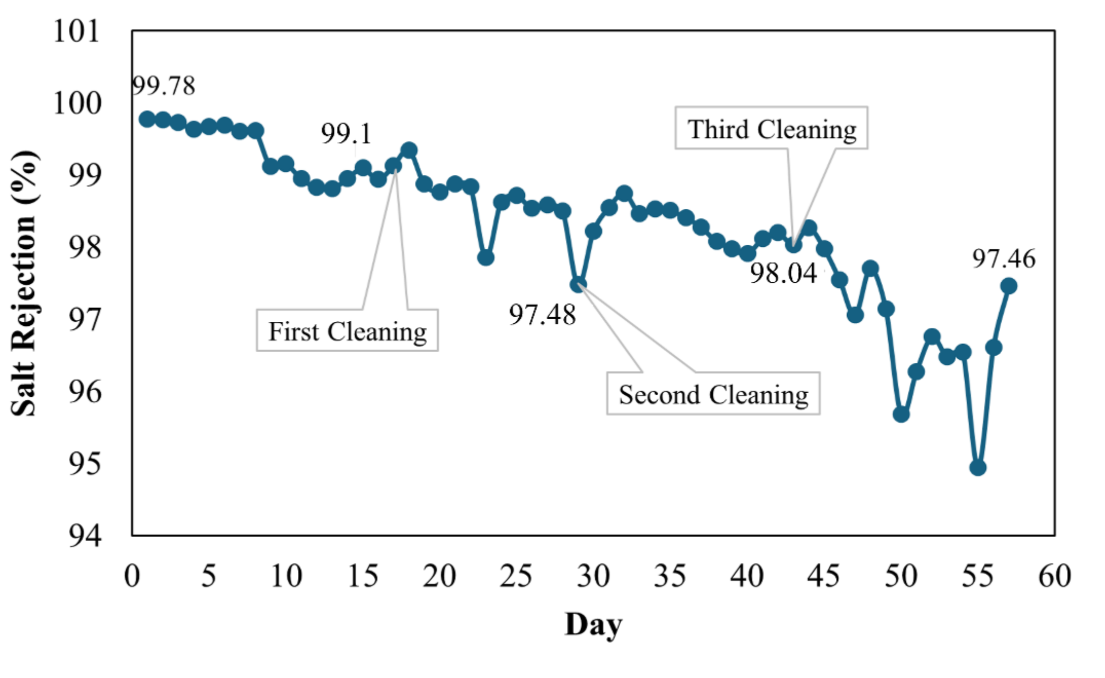

Figure 2. Salt Rejection at RO B Membrane

The RO-A membrane shows results that correspond with the membrane specifications, specifically the minimal salt rejection value. According to the given requirements, such as 99.0%. However, as time passed by and cleaning was carried out, the salt rejection value on the RO A membrane reduced to 98.99% within 8 weeks, but was still within a good threshold. Higher the salt rejection evaluation, the better the quality of the produced water. This happens due the mineral salt content in the water will be lost [20]. Figure 2 illustrates the salt rejection percentage value on the RO B membrane results that are in agreement with the standard membrane specifications before cleaning, however after the first to third washing the salt rejection value decreases below the standard membrane specification value, that is 97.46%. The decrease in the salt rejection percentage implies that the salts carried by the feed water cannot be rejected and are then polarized into the membrane pores so that the membrane pores are blocked by an additional layer of salt. Based on the results obtained on the two RO membranes, RO A membrane suggests salt passage levels which tend to be better when compared with RO B membrane.

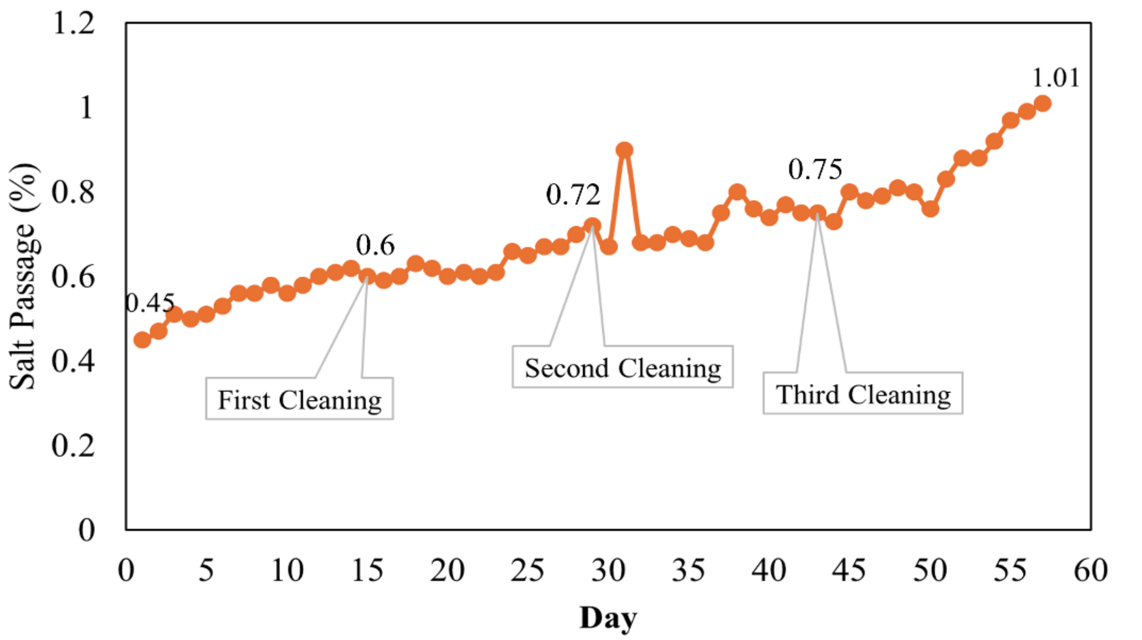

Figure 3. Salt Passage at RO A membrane

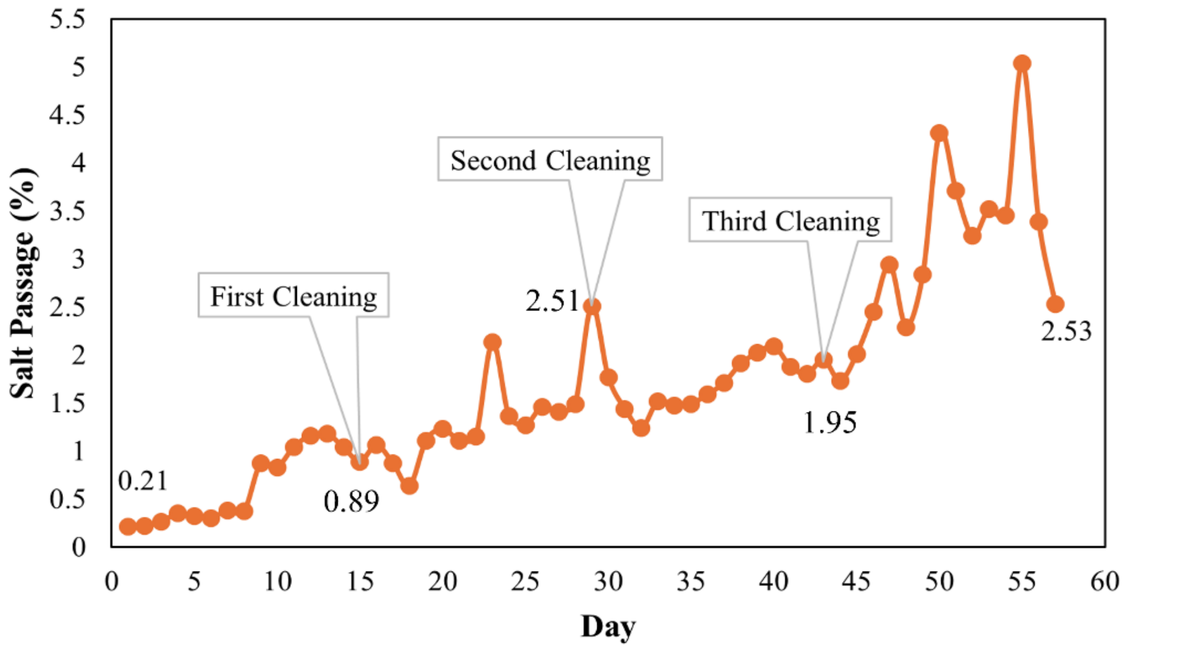

Figure 4. Salt Passage at RO B Membrane

Salt passage is the opposite of salt rejection, specifically the percentage of minerals and salts that flow through the product's membrane. Figure 3 demonstrates that the salt passing value on the RO A membrane rose over time by up to 1% and did not experience a significant decline after washing. Based on the standard salt rejection value, the maximum salt passing level is 1%. Based on the maximum salt passage value, the RO-A membrane can be regarded to be still in good condition. Figure 4 demonstrates that the salt passage value of the RO B membrane saw a very large increase before and after cleaning the membrane and was considerably beyond the maximum salt passage value, particularly 0.89–2.53%. This is due to membrane degradation, which will alter the salt passage value and result in changes in the membrane structure so that the salt passage value surpasses the maximum parameter value. Higher salt passage values, the more mineral salt content passes through, leading to poor water quality. Salt passage is also controlled by the salt level of the stream of water. These effects are greatly affected by feed material, membrane charge, and membrane chemical characteristics[21]. Continuous use and regular cleaning will cause the membrane to break down such that salt passage increases over time. In addition, the research findings indicate that following the membrane cleaning process, there is a subsequent reduction in salt rejection and an increase in salt passage. Several factors may affect this fact, such as membrane failure, the accumulation of particulates, minerals, or organic materials on the membrane's surface, which can decrease its efficiency, and the quality parameters of the input water (pH, TDS, and temperature).

The large discrepancy in the results of salt rejection and salt passage values for RO A and RO B membranes can potentially be caused by variances in the service life of the membranes. When this investigation was conducted out, the RO A membrane was less than 6 months old, while the RO B membrane was more than 1 year old. Newer reverse osmosis membranes generally have more effective salt rejection rates, lower salt flow rates, higher permeate flow rates, and reduced possibility of fouling compared to long-used membranes. This is in accordance with the statement of Antony et al. (2016), which claims that membranes that have a longer service life tend to incur higher fouling and degradation than membranes that have a new service life under equal operating conditions [22]. RO membranes that have a longer life expectancy experience a decrease in flux, an increase in operating pressure, and a decrease in rejection of these ions caused by fouling and scaling that occurs on the membrane surface due to the deposition of salts and other particles, so a cleaning process and good pretreatment for raw water periodically must be performed[23, 24].

Membrane flux is one of the indicators used for determining the performance of reverse-osmosis membranes. The amount of flux value depends on the product flow (permeate) produced. The higher the flow value, the more water output will grow. The results of the membrane washing analysis of RO A and RO B membrane fluxes can be shown in Figures 5 and 6.

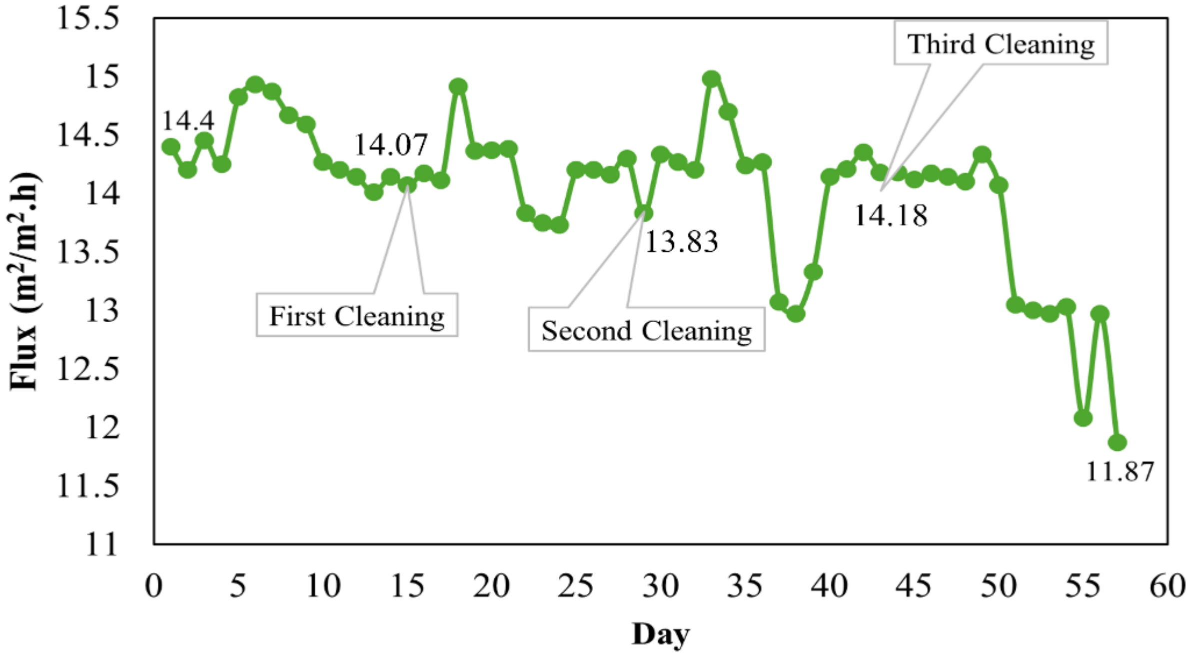

Figure 5. Flux at RO A Membrane

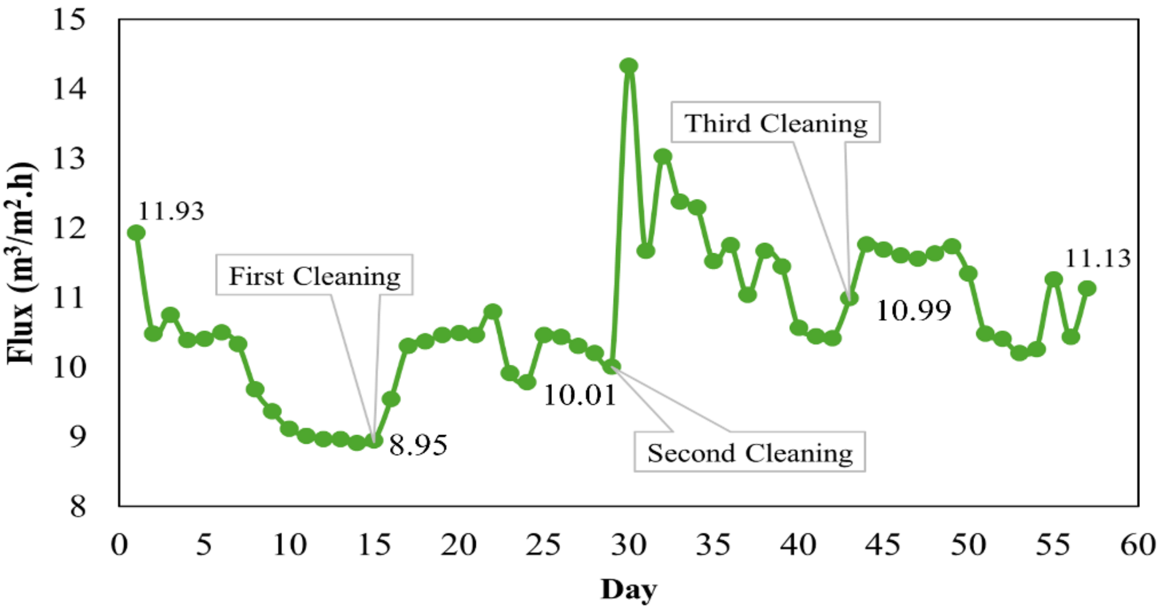

Figure 6. Flux at RO B Membrane

The flux value reveals results that increase after cleaning but immediately drop within a few days after the washing process. This shows that fouling has formed on the membrane, resulting in a drop in the flux value. On RO membrane A, flux values were obtained in the range 14.4–11.87 m^3/m^2h, while on RO membrane B, flux values were obtained in the range 11.93–11.13 m^3/m^2h. The flux value in this study is variable and decreasing with time, even though multiple cleanings have been carried out. This can be caused by numerous circumstances. One of them is the working conditions of the reverse osmosis system utilized in the PT. XYZ clean water pump facility runs automatically, therefore operating parameters such as operating pressure and feed flow rate cannot be controlled. Membrane flux is closely connected to pressure and feed flow rate; the higher the flow rate, the larger the mass transfer coefficient and concentration polarization. The higher the feed flow rate, the higher the flux, but also the higher the energy consumption and shear stress that occur in the membrane.

In general, an increase in operating pressure leads to an increase in permeate flux. As the running time grows, the flux value decreases. However, it will promote fouling and concentration polarization on the RO membrane[25]. A decrease in flow may indicate fouling on the membrane surface. The decrease in flux can be induced by solute concentration, which subsequently impacts osmotic pressure, resulting in the opposite force of transmembrane pressure[26]. The higher the osmotic pressure, the lower the driving force and flux[26, 27]. The reverse osmosis apparatus utilized also functions automatically, therefore working factors like as operating pressure and feed flow rate cannot be controlled. This causes the salt rejection, salt passage, and flow parameter values to not reflect linear changes and experience a reduction in performance of the membrane over time.

The efficiency of chemical cleaning is controlled by the type of chemical used as well as operational parameters such as temperature and concentration. The selection of cleaning chemical is dependent on the material of the membrane and the type of fouling on the membrane. The fouling that forms on membranes nowadays is colloidal fouling (ions and heavy metals) forms on membranes currently in use. To clean this form of contamination, acidic cleaning agents such as citric acid are utilized. Various types of acid solutions (hydrochloric, nitric, phosphoric, sulfuric, and citric acids) for chemical cleaning of RO membranes and recovery of the maximum flux are obtained using citric acid. Previous research conducted by Jia (2022) indicated that washing with citric acid might enhance the flux rate by 50–80%[29]. For maximum cleaning results, citric acid needs to be used in combination with other chemicals, such as sodium hydroxide, sodium hypochlorite, or sodium dodecyl sulfate, depending on the type of fouling created.

4. Conclusions

Based on the current study, it can be inferred that the utilization of citric acid as a chemical in the process of cleaning RO membranes is not highly efficient. This can be seen from several indicators that reflect the performance of the FILMTEC BW30-4400 IG-type reverse osmosis membrane. The age of membrane utilization also considerably affects membrane performance. RO B membranes, which have a longer service life, tend to offer less good performance when compared to RO A membranes, as indicated by differences in salt passage, salt rejection, and flux rates before and after the membrane cleaning procedure.

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