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Recycling End-of-Life (EoL) Reverse Osmosis (RO) Membranes into Ultrafiltration Membranes using Potassium Permanganate (KMnO4) for Aquaculture Water Filtration

Raden Rara Dewi Artanti Putri*, Bayu Triwibowo, Haniif Prasetiawan, Dian Fatimatus Salwa, Whilda Fauziah, Daffa Zamiira Pradana, Divifan Armyko Aldiansar

Universitas Negeri Semarang, Indonesia

*Corresponding Author: dewi.artanti@mail.unnes.ac.id

Abstract

Sustainable and economical management of aquaculture water is a significant challenge in the fisheries industry. This study aims to convert End-of-Life (EoL) Reverse Osmosis (RO) membranes into Ultrafiltration (UF) membranes using a potassium permanganate (KMnO4) solution as an oxidizing agent to enhance the efficiency of aquaculture water filtration. The conversion process involves immersing the used RO membranes in a 4,5% w/v KMnO4 solution for 3 days at room temperature. Prior to conversion, the membranes were cleaned using a 0,1% w/v Sodium Dodecyl Sulfate (SDS) solution and 0,05 M Ethylenediaminetetraacetic Acid (EDTA) to remove organic and inorganic contaminants. The results showed an increase in water flux from 20 L/m^2•h to 50 L/m^2•h after conversion. The analysis of aquaculture water quality after filtration using the converted UF membranes showed a significant reduction in Biological Oxygen Demand (BOD) from 5,547 mg/L to 3,817 mg/L, representing 31,2% reduction, and Chemical Oxygen Demand (COD) from 29,91 mg/L to 24,22 mg/L, representing 19% reduction. The membranes were highly effective in removing coliforms, achieving a 100% reduction from 180 MPN/100mL to 0 MPN/100mL. The values of DO and TDS decreased by only about 2%, salinity values remained unchanged, while total ammonia increased. The conversion process increases efficiency filtration, reduces operational costs, and decreases membrane waste.

Keywords: reverse osmosis; ultrafiltration; membrane; aquaculture water; potassium permanganate

INTRODUCTION

Membrane technology plays a vital role in water treatment and desalination, with more than 60% of purified water currently produced through membrane-based processes (Le & Nunes, 2016). Membrane technologies have been extensively applied in desalination due to their high sustainability in terms of environmental impact, land use efficiency, operational simplicity, flexibility, and adaptability when compared to thermal or chemical approaches (Yusuf et al., 2020).

Among these technologies, reverse osmosis (RO) membranes are the most widely used for desalination purposes. Over the past two decades, the number of desalination plants has increased by approximately 70%, with more than 9,000 facilities currently in operation (Lawler et al., 2012). This expansion has led to a significant rise in RO membrane waste generation, with over 840,000 end-of-life RO membranes discarded annually, amounting to more than 14,000 tons per year (Paula & Amaral, 2022).

Recycling represents a promising strategy to mitigate RO membrane waste accumulation and contributes to the circular economy paradigm. From an economic standpoint, the average production cost of commercial RO membranes is approximately USD 25.13/m^2, whereas recycled membranes can be produced at a substantially lower cost of around USD 0.22/m^2 (Moreira et al., 2021) This cost gap highlights the importance of optimizing recycling practices. End-of-life RO membranes can be downgraded into porous

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[*] Corresponding Author: +62 856-4156-6430
Email: dewi.artanti@mail.unnes.ac.id

membranes such as ultrafiltration (UF) membranes, which can be reused to extend membrane lifespan and reduce the environmental burden associated with new membrane production. Recycled UF membranes also offer potential applications in aquaculture systems by efficiently removing impurities from pond water, thereby enhancing cultivation effectiveness.

UF membranes offer several advantages over other membrane types, such as microfiltration (MF) and nanofiltration (NF), particularly in aquaculture water treatment. UF membranes possess pore sizes ranging from 0.01 to 0.1 microns, enabling them to effectively remove turbidity, bacteria, viruses, and various organic particulates commonly present in aquaculture waters (Wulandari et al., 2018). Empirical data reveal that UF membranes can reduce Total Suspended Solids (TSS) from 100 mg/L to 10 mg/L and Chemical Oxygen Demand (COD) from 150 mg/L to 40 mg/L—performance levels that cannot be achieved with MF membranes, which typically only reduce TSS to around 50 mg/L. Furthermore, the water flux of UF membranes increases significantly after conversion, from 20 $L/m^2 \cdot h$ (for spent RO membranes) to 50 $L/m^2 \cdot h$, enhancing overall filtration efficiency (Fadillah & Slamet, 2023). These advantages make UF membranes highly effective for maintaining aquaculture water quality, supporting healthier aquatic environments, and reducing contamination risks that may compromise aquaculture productivity.

The process of recycling RO membranes into UF membranes involves the degradation of the aromatic polyamide (PA) layer. Contemporary RO membranes are typically constructed as thin-film composite polyamide membranes comprising three layers: (i) a thin, dense, selective aromatic polyamide layer; (ii) a microporous polysulfone (PSf) support layer; and (iii) a polyester (polyethylene terephthalate) base layer (Shenvi et al., 2015). Among the various PA degradation methods, chemical oxidation has been widely recommended due to its high efficiency, low energy requirement, cost-effectiveness, and ability to produce properties comparable to commercial UF membranes (Larrañaga et al., 2022). The effectiveness of chemical oxidation depends on the oxidant concentration and exposure time.

Potassium permanganate ($KMnO_4$) has been reported as a potent oxidative agent capable of degrading and separating the PA layer from the PSf support via amide bond cleavage. This process involves $KMnO_4$ reacting with amide bonds in the PA layer, thereby breaking these bonds and enabling the detachment of the thin PA film from the PSf substrate (Paula et al., 2017). $KMnO_4$ has demonstrated operational stability under various industrial water treatment conditions, including fluctuations in pH and temperature. Additionally, it exhibits selectivity in modifying the RO membrane's active layer without damaging critical components of spiral-wound membrane modules, such as feed spacers, permeate spacers, and O-rings (Khoo et al., 2021). This enables in-situ membrane conversion, reducing operational downtime and eliminating the need for disassembly and reinstallation.

Based on the foregoing analysis, this study aims to recycle spent RO membrane modules into UF membranes through chemical oxidation using $KMnO_4$ for application in aquaculture water filtration, offering superior performance specifications. The evaluation focuses on the type of feed solution and operating pressure. Additionally, the study assesses and validates performance metrics including water permeability, salt rejection, protein rejection, and the analysis of water quality parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), salinity, total ammonia, and total coliform content in aquaculture effluents.

METHODS

In conducting this study, a range of instruments and materials were prepared to ensure precision and reliability throughout each stage of the experimental procedures. The instruments used included a set of Pyrex glassware, a tubular membrane casting mold, an analytical balance (OHAUS PX224/e), a pH meter (Mettler Toledo SevenCompact S220), an electrical conductivity meter (RIO 6022 Conductivity), and a custom-built automated cross-flow filtration unit (developed by the authors).

The materials used in this study comprised a reverse osmosis (RO) membrane module with a diameter of 4.2 cm, consisting of three layers: a polyethylene (PE) support layer, a polysulfone (PSf) porous intermediate layer, and a dense polyamide (PA) selective top layer. Additional chemicals included potassium permanganate ($KMnO_4$, 4.5% w/v, Merck), distilled water (aquadest), and sodium chloride (NaCl, solid, Merck).

Cleaning Process of End-of-Life (EoL) RO Membranes

The cleaning process of End-of-Life (EoL) reverse osmosis (RO) membranes was carried out using Sodium Dodecyl Sulfate (SDS) and Ethylenediaminetetraacetic Acid (EDTA) solutions. The procedure began with the preparation of used RO membranes. These membranes were first immersed in a 0.1% w/v SDS solution for 6 hours at 40°C to remove oils, greases, and organic contaminants. Following the immersion, the membranes were rinsed with deionized water to eliminate any residual SDS. Subsequently, the membranes were immersed in a 0.05 M EDTA solution for 6 hours at room temperature to remove metal ions and inorganic deposits. After the EDTA treatment, the membranes were again rinsed with deionized water to remove residual cleaning agents. The cleaned membranes were then air-dried at room temperature and prepared for further conversion or filtration characterization.

Conversion of End-of-Life (EoL) RO Membranes into UF Membranes

The membrane recycling process was conducted by immersing the cleaned RO membranes in a 4.5% w/v potassium permanganate ($KMnO_4$) solution, which served as an oxidizing agent to remove the dense aromatic polyamide top layer. This step aimed to convert the membranes into porous ultrafiltration (UF) membranes. The immersion process was carried out over a period of 3 days.

Filtration Testing Using an Automated Cross-Flow Unit

The filtration mechanism was evaluated using an automated cross-flow operation unit. In this system, the feed solution flows axially (parallel) to the membrane surface (Wenten, 2015). This flow orientation induces shear forces and/or turbulence near the membrane surface, thereby minimizing the formation of a filter cake (i.e., the accumulation of particles on the membrane surface) (Notodarmojo et al., 2014). A schematic diagram of the automated cross-flow unit system is presented in Figure 1.

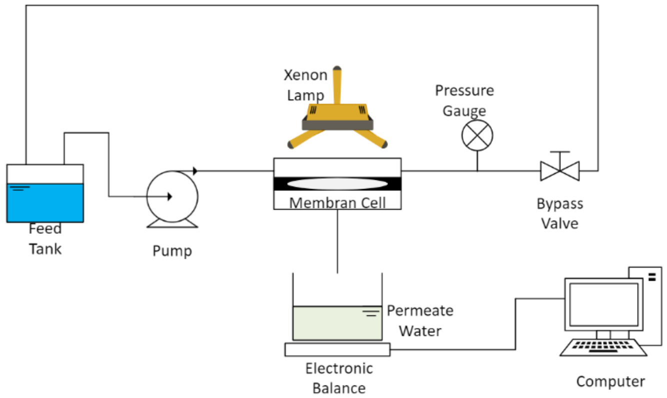

Figure 1. Systematic diagram of the automated cross-flow unit operation

The operation of the unit begins by placing a membrane with a diameter of 4.2 cm into the membrane cell. The membrane is supported by rubber gaskets to withstand the pressure generated by the pump. The feed solution stored in the tank is pumped at varying pressures (2, 3, 4, and 5 bar). The pressure can be adjusted using a valve installed in the unit. The feed flows across the membrane surface, and the retentate (unfiltered solution) is recirculated back into the tank. The automated cross-flow unit operation is integrated with the Internet of Things (IoT), and the mass of the permeate is monitored in real time using an electronic balance sensor. The schematic arrangement of the automated cross-flow unit operation is presented in Figure 2.

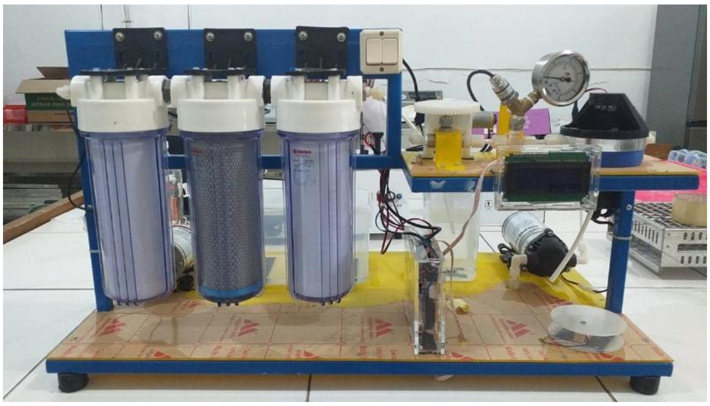

Figure 2. Schematic of the automated cross-flow unit operation

Flux and Rejection Calculation

The permeability test was carried out by circulating distilled water (aquadest) through the automated cross-flow unit. Prior to testing, the membrane underwent a compaction process for 30 minutes to stabilize its pores and structure. The operating conditions were set at varying pressures (2, 3, 4, and 5 bar) and room temperature (25°C). Permeate was collected every 15 minutes and used to calculate the flux using the following equation 1.

$$\mathrm{J} = \frac{\mathrm{V}}{\mathrm{Axt}} \tag{1}$$

Description:
J : Flux (l/m^2h)
V : Permeate volume(L)
A : Membrane surface area (m^2)
t : Time (h)

The salt rejection test was carried out using a model brackish water solution containing 1 g/L NaCl, at pH 7 and a temperature of 25°C. The salt rejection was then calculated using the following formula in eq 2

$$\mathrm{R} = 1 - \frac{\mathrm{Cp}}{\mathrm{Cf}} \times 100\% \tag{2}$$

Description:
R : Rejection coefficient (%)
Cp : Solute concentration in permeate
Cf : Solete concentration in feed

Salt analysis was performed using an electrical conductivity meter. The analysis of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), salinity, total ammonia, and total coliform was conducted at the Center for Standardization and Industrial Pollution Prevention Services (Balai Besar Standardisasi dan Pelayanan Jasa Pencegahan Pencemaran Industri), Semarang.

RESULT AND DISCUSSION

Cleaning Process of End-of-Life (EoL) RO Membranes

The cleaning process of End-of-Life (EoL) Reverse Osmosis (RO) membranes using Sodium Dodecyl Sulfate (SDS) and Ethylenediaminetetraacetic Acid (EDTA) involves effective chemical interactions to remove various contaminants accumulated during membrane operation. This procedure aims to restore membrane performance and extend its lifespan. SDS is an anionic surfactant with the chemical formula $C_{12}H_{25}NaO_4S$. It is capable of lowering water surface tension and breaking down fat and protein molecules adhered to the membrane surface (Muharja et al., 2024). When membranes are immersed in a 0.1% w/v SDS solution at 25°C for 6 hours, SDS molecules penetrate and disintegrate organic foulants such as oils and fats. The sulfate group in SDS interacts with hydrophobic molecules, breaking intermolecular bonds and making the contaminants water-soluble (Jadhao et al., 2023). This process effectively removes organic impurities from the membrane surface.

EDTA, a chelating agent with the chemical formula $C_{10}H_{16}N_2O_8$, can bind metal ions and form stable complexes, allowing it to remove inorganic deposits. After SDS immersing, the membranes are rinsed with deionized water and subsequently immersed in a 0.05 M EDTA solution at room temperature for 6 hours. EDTA binds with metal ions such as Ca^{2+} and Mg^{2+}, which are commonly responsible for inorganic fouling in RO membranes. This chelation process transforms the metal ions into water-soluble complexes, enabling their removal from the membrane surface (Jordan, 2024). The combined cleaning using SDS and EDTA has been proven effective in eliminating both organic and inorganic contaminants from RO membrane surfaces.

Conversion of EoL RO Membranes into Ultrafiltration Membranes

The conversion of End-of-Life (EoL) Reverse Osmosis (RO) membranes using potassium permanganate ($KMnO_4$) is an innovative method to modify membrane characteristics for Ultrafiltration (UF) applications. When used RO membranes are immersed in a 4.5% w/v $KMnO_4$ solution for 3 days at room temperature to achieve permeability consistent with UF specifications (Couthinho et al., 2017), permanganate ions (MnO_4^-) react with organic and inorganic materials on the membrane surface. This oxidation process breaks down complex contaminant molecules into simpler, water-soluble compounds, facilitating their removal. Additionally, $KMnO_4$ modifies the polymer structure of the membrane by opening previously blocked pores, as described in the following reaction:

$$2MnO^{4-} + C \rightarrow 2MnO_2 + CO_2$$

This reaction illustrates how $KMnO_4$ oxidizes carbon compounds (C), which are components of organic contaminants on the membrane. The oxidation process by $KMnO_4$ leads to increased membrane porosity, changing the pore size from 0.001 microns (standard RO pore size) to approximately 0.01 microns, which meets the requirements for ultrafiltration (Meidinariasty et al., 2019). This alteration enables the membrane to filter larger particles and enhances filtration capacity.

Besides facilitating the removal of organic and inorganic contaminants, the oxidation process involving potassium permanganate can substantially alter the pore structure and surface morphology of the membrane. While an increase in porosity is desirable for enhancing water permeability, over-oxidation may result in excessive pore enlargement that compromises selectivity for smaller solutes (Meidinariasty et al., 2019). Furthermore, the deposition of manganese dioxide (MnO_2) as a byproduct of permanganate oxidation can partially block membrane pores or accumulate on the membrane surface, leading to reduced effective filtration area and possible flux decline. It is also recognized that prolonged or uncontrolled oxidation may weaken the mechanical integrity of the membrane, potentially causing compaction or structural deformation under high operating pressures. Therefore, it is crucial to carefully optimize the oxidation conditions—such as $KMnO_4$ concentration and immersion time—to maximize permeability while maintaining desired solute rejection and mechanical stability. These considerations underscore the need for a balanced approach in membrane recycling processes to ensure long-term reliability in practical ultrafiltration applications.

Effect of Pressure on Membrane Permeability

The permeability of UF membranes is highly influenced by operating pressure. At optimal pressure, UF membranes can effectively separate particles and macromolecules from water. However, excessive pressure can lead to several issues, such as fouling, membrane compaction, and structural damage. Studies have shown that proper pressure regulation is crucial to maintaining a balance between membrane permeability and fouling rate. Flux measurement is conducted to determine the membrane's capability to pass a certain volume of feed solution (Kusumawati & Tania, 2018). his membrane operates under a pressure range of 1–5 bar. According to Fathanah et al., 2021 ultrafiltration membranes reject particles in the range of 0.01–0.1 µm, with an average flux of 10–50 L/m^2•h.

Permeability refers to the ability of aquaculture water to pass through the membrane, which is affected by the applied operating pressure (Fathanah et al., 2021). Flux measurements were carried out using a cross-flow method for 20 minutes, during which permeate data were collected for each pressure variation. In the operation, aquaculture water was used as the feed solution. The flux and permeability data are presented in Table 1.

Table 1. Operating pressure data on permeability

P	**J**	**Permeability**
(bar)	**(l/m2•h)**	**(l/m2•h•bar)**
2	19,24	9,62
3	24,81	8,27
4	33,74	8,43
5	49,97	9,99

The results showed that the membrane flux increased in a fluctuating manner and was directly proportional to the immersion time. The increase in flux was due to the opening of membrane porosity as a result of $KMnO_4$ exposure. The longer the exposure time, the more open the membrane porosity became. This occurred because treatment with $KMnO_4$ on the reverse osmosis (RO) membrane caused damage to the hydrogen bonds in the molecular structure of the polyamide chains in the membrane, thereby enlarging the pore size (García-Pacheco et al., 2015).

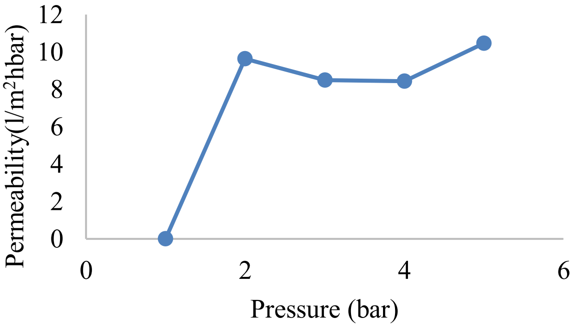

Figure 3. Graph of the effect of pressure on permeability

Based on Figure 3, it can be seen that the higher the applied operating pressure, the greater the resulting flux value. The highest water flux was obtained at a pressure of 5 bar, reaching 49.9 L/m^2•h. The increase in flux value was influenced by membrane deformation due to the high pressure in the feed flow, which widened the membrane pores (Kusumawati & Tania, 2018). However, it is important to note that the increase in permeability is not always linear with increasing operating pressure. From Figure 3, it can be seen that membrane permeability increased with increasing operating pressure, reaching its maximum value at 2 bar. Beyond that, the permeability value decreased at 3 bar. Nevertheless, overall permeability was maintained in the range of 8–9 L/m^2•h•bar, which ensures stable and economical experimental operation (Wang et al., 2019).

Beyond the observed increase in flux with higher applied pressure, permeability does not always rise proportionally and may even decline at higher pressures due to two key phenomena: membrane compaction and fouling. Under excessive pressure, the polymer matrix of the membrane can become compressed, reducing the effective pore volume and causing a decrease in permeability. Persson (1995) demonstrated that ultrafiltration membrane compaction under high pressure irreversibly decreases porosity and restricts water passage, with pronounced impacts at pressures above 2 bar. Moreover, higher pressure accelerates particulate and organic fouling on the membrane surface and within its pores, as more solute is forced toward the membrane, promoting cake layer and internal pore blockage.

Another important factor is concentration polarization: accumulation of solutes and particulates near the membrane surface as pressure increases. This effect raises local osmotic pressure, lowers driving force for permeation, and increases membrane resistance, further limiting permeability even if flux appears elevated (Quezada et al., 2021). The formation of a dense cake layer and gel layer can lead to irreversible fouling, making high-pressure operation less effective in long-term use. Therefore, optimal pressure must be carefully selected to balance the trade-off between high flux and sustained permeability, minimizing compaction and fouling for stable membrane operation.

Effect of pressure on NaCl rejection

Membrane selectivity (rejection) refers to the membrane's ability to separate specific components from the feed stream (Wenten, 2015). In this study, the conductivity of the obtained flux was used to assess salt removal. Electrical conductivity is the ability of water to conduct electric current. The more dissolved salts that can ionize, the higher the conductivity value. The effect of 4.5% w/v $KMnO_4$ on rejection is presented in Table 2.

Table 2. Salt rejection data

Imersion time (jam)	**Pressure (bar)**	**NaCl**	
		Conductivity (μS/cm)	**Rejection (%)**
168	2	1306	22%
168	3	1449	14%
168	4	1403	16%
168	5	1417	15%

Table 2 presents the effect of operating pressure on membrane performance in a 4.5% w/v $KMnO_4$ solution. It can be observed that NaCl rejection values fluctuate with pressure, and the corresponding trend is illustrated in Figure 4.

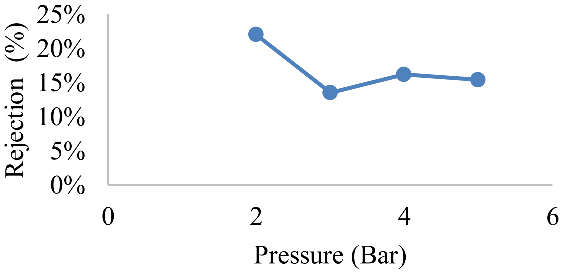

Figure 4. Influence of pressure on NaCl rejection performance

Based on the data in Table 2, it was revealed that at an operating pressure of 2 bar, the membrane exhibited a NaCl rejection rate of 22%. However, as the pressure increased to 5 bar, the rejection rate decreased to 15%. These findings suggest that while increasing pressure may enhance the permeation rate, it does not necessarily improve salt rejection in ultrafiltration membranes. The low NaCl rejection values (14–22%) observed in this study reflect the intrinsic limitations of ultrafiltration (UF) membranes for ionic salt removal. Due to their relatively large pore size, UF membranes act primarily as physical barriers for suspended solids, macromolecules, and microorganisms, but cannot effectively block monovalent ions such as Na^+ and Cl^-. This distinguishes UF from nanofiltration (NF) and reverse osmosis (RO) membranes, which are designed for significant ionic and salinity rejection. Consequently, the converted UF membrane is not suitable for direct use in brackish or saline water applications where substantial salt removal is required. Instead, its optimal use is for pathogen control, turbidity reduction, and organic contaminant removal in freshwater or low-salinity aquaculture systems, or as a pre-treatment step before NF/RO processes when desalination is necessary.

Table 3. Initial and post-filtration water quality parameters

Parameter	Initial Sample	Post-Filtration
BOD (mg/L)	5,547	3,817
COD (mg/L)	29,91	24,22
DO (mg/L)	6,839	6,646
TDS (mg/L)	27248	26540
Salinity (%)	20,0	20,7
Total Ammonia (mg/L)	0,289	0,409
Total Coliform (MPN/100mL)	180	0

The observed decrease in NaCl rejection at higher pressures can be explained by several underlying mechanisms. Unlike reverse osmosis (RO) or nanofiltration (NF) membranes, ultrafiltration (UF) membranes possess relatively large pore sizes (typically 0.01–0.1 µm) that primarily retain macromolecules and particulates, but allow most dissolved salts, including sodium chloride, to pass through freely. As pressure increases, water flux increases, but the sieving mechanism of UF means that smaller ions such as Na^+ and Cl^- are not effectively excluded, resulting in low and sometimes further reduced rejection at higher pressures (Narong et al., 2006). In addition, higher operating pressures may lead to increased concentration polarization, where dissolved ions accumulate near the membrane surface. This can locally elevate the driving force for ion passage into the permeate, reducing the effective rejection rate (Prastyo & Hasari, 2023). The phenomenon is exacerbated by potential minor compaction of membrane pores that still remain above the size cutoff for salt exclusion. It is also important to highlight that the salt rejection observed here (14–22%) is typical for UF membranes and underscores their unsuitability for desalination or brackish water applications (Thomas et al., 2016). UF membranes are best applied for removal of colloidal particles, bacteria, and organic macromolecules, rather than salts. Thus, the decrease in NaCl rejection at higher pressures, far from being a limitation of the experimental setup, reflects a fundamental property of UF membrane separation and should guide the selection of membrane type for intended water treatment goals.

Analysis of BOD, COD, DO, TDS, Salinity, Total Ammonia, and Total Coliform in Aquaculture Water

This section examines the water quality parameters of aquaculture water, including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), salinity, total ammonia, and total coliform. The analysis is crucial to assess whether the recycled membrane meets the functional specifications of ultrafiltration membranes, particularly for the removal of microorganisms in aquaculture systems. The results of the initial and post-filtration samples are presented in Table 3.

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The RO membrane, which was degraded using $KMnO_4$ and subsequently repurposed as a UF membrane, was applied to reduce BOD and COD levels in aquaculture water. The filtration process used pre-treated aquaculture water to minimize membrane fouling caused by excessive contaminants.

The initial BOD and COD levels were 5.547 mg/L and 29.91 mg/L, respectively. Post-filtration, BOD decreased to 3.817 mg/L, corresponding to a 31.2% reduction, while COD decreased to 24.22 mg/L, representing a 19% reduction. These results indicate that the downgraded UF membrane effectively reduced organic pollution levels in aquaculture water.

The post-filtration BOD level met the regulatory standard for aquaculture water quality, which is less than 45 mg/L (KEP.28/MEN/2004). Furthermore, it also complied with marine water quality standards for aquatic biota, which require BOD levels to be below 20 mg/L (KEP.51/MENKLH/2004).

The BOD/COD ratio reflects the biodegradability of the water; a higher ratio indicates greater biodegradability (Tamyiz, 2015). Based on the data, the BOD/COD ratio before filtration was 0.184 and decreased to 0.157 after filtration. An ideal BOD/COD ratio for aquaculture and biological treatment processes ranges between 0.2–0.5, known as the biodegradable zone (Samudro & Mangkoedihardjo, 2010). A very low BOD/COD ratio (less than 0.01) suggests the presence of persistent organic pollutants that are non-biodegradable (Srinivas, 2008).

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is a key indicator for assessing water cleanliness. Higher DO levels indicate better water quality (Naillah et al., 2021). DO is closely related to biochemical oxygen demand (BOD); when BOD is high, DO tends to decrease, as dissolved oxygen is consumed by bacteria during the decomposition of organic matter, leading to oxygen depletion for aquatic organisms. Both indicators are important for evaluating water quality, although BOD more specifically reflects the level of organic pollution (Febrion & Sekarningtias, 2018). In this study, the DO concentration of the pond water was 6.839 mg/L, and after ultrafiltration (UF) it was 6.646 mg/L. According to the Indonesian Ministry of Health Regulation No. 32 of 2017, water with DO values above 4 mg/L is considered to be of good quality with a low level of pollution. These results indicate that the UF membrane was able to retain a substantial level of dissolved oxygen in the treated water.

Total Dissolve Solid (TDS)

The TDS levels measured before and after filtration were 27,248 mg/L and 26,540 mg/L, respectively. This indicates that the downgraded UF membrane was not effective in removing TDS, achieving only a 2.60% reduction. The ineffectiveness may be attributed to the presence of dissolved substances in the water that the membrane could not retain (Nisah & Nasution, 2022).

Salinity

Salinity is a measure of the concentration of salts in water, typically expressed in parts per thousand (‰), representing the weight of salts per 1,000 grams of seawater (Wibisono, 2005). Pond water generally has lower salinity levels than the average seawater salinity, which is approximately 35‰ (Elsandari & PURNOMO, 2015). In this study, the salinity of the pond water was 20‰ and remained unchanged after filtration.

Total Ammonia

Ammonia becomes highly toxic to aquatic life at elevated concentrations (Gappar & Christyanda, 2020). The acceptable threshold of ammonia concentration in aquaculture water is 0.1 mg/L (Rohani et al., 2016). In this study, total ammonia concentrations were 0.289 mg/L before filtration and increased to 0.409 mg/L after filtration. These values indicate that the water is unsuitable for aquaculture purposes. The post-filtration increase may be due to the release of ammonia from decomposed organic matter during the filtration process (Sitasari & Khoironi, 2021). The post-filtration increase in ammonia can also be attributed to the breakdown of organic nitrogen compounds during filtration and agitation, facilitating their conversion to dissolved ammonia in the water column. Elevated ammonia concentration poses a significant threat in aquaculture, as prolonged exposure at levels above 0.1 mg/L can induce toxico-physiological effects in fish and other aquatic organisms, including impaired growth, behavioral stress, increased susceptibility to disease, and mortality. To mitigate the risk of ammonia accumulation in treated water, it is recommended to employ post-filtration biological treatments, such as biofilters with ammonia-oxidizing bacteria (Nitrosomonas, Nitrobacter) or the integration of aquaponic systems with aquatic plants, which help assimilate ammonia and reduce its concentration. The implementation of biofloc technology or effective microorganisms (EM4) further promotes biological nitrification and denitrification, effectively decreasing ammonia and nitrate levels in shrimp and fish farm wastewater. Future research should focus on combining UF membranes with biological ammonia mitigation strategies to ensure water quality meets safe standards for aquaculture.

Total Coliform

The downgraded UF membrane demonstrated 100% efficiency in removing coliform bacteria. The initial coliform concentration in the pond water was 20 MPN/100 mL, which was reduced to 0 MPN/100 mL after filtration. This result confirms the membrane's ability to remove coliform bacteria ranging from 0.5 to 1 micron in size (Anggraini & Sugito, 2019).

CONCLUSION

The converted UF membrane exhibited enhanced water flux, increasing from 20 to 50 L/m²- h, and demonstrated high efficiency in removing coliform bacteria (achieving 100% removal from 180 MPN/100 mL to 0 MPN/100 mL) and reducing organic contaminants (BOD reduced by 31.2%, COD by 19%). However, reductions in DO and TDS were minimal (approximately 2.6%), salinity slightly increased, and total ammonia levels post-filtration exceeded safe thresholds for aquaculture. These results indicate that while UF membranes are highly effective for microbiological safety and the removal of particulate and organic contamination, they are limited in reducing dissolved salts and ammonia—parameters which are also essential for overall pond water suitability. Therefore, UF technology is best applied as a pre-treatment or pathogen control step in aquaculture systems, rather than as a comprehensive solution for all water quality parameters. For optimal pond water management, ultrafiltration should be integrated with additional biological and chemical treatment processes (e.g., biofilters, aquaponics, or selective ion-exchange membranes) to address dissolved contaminants including salinity and ammonia. Overall, UF membrane conversion provides significant advantages in terms of pathogen control, operational cost reduction, and membrane waste minimization, contributing to selective sustainable practices when integrated with broader treatment technologies in aquaculture industries.

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