CLEAN WATER PRODUCTION PERFORMANCE MEASUREMENT INDICATORS AND FACTORS: A REVIEW ON ULTRAFILTER MEMBRANE

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ABSTRACT: *This review aims to answer the question relating to the problem of measuring the clean water production performance of the Ultrafilter membranes. This review has designed to study the research journal articles recently published (from 2000 to 2022) on the clean water production performance of ultrafilter membranes. The focus of this study was to unlock the influence of feed water quality, pre-treatment efficiency, Productivity, and energy consumption of the ultrafilter membrane on clean water production performance. The outcome of this review revealed that four indicators and thirteen potential factors have used for measuring the clean water production performance of ultrafilter membranes. The potential factors are the feed water pre-treatment, feed water pressure, chemically enhanced backwash, and osmotic pressure. Additionally, the pH, total suspended solids, turbidity, and chemical oxygen demand of feed water are the sources of cake layer formation that affect energy consumption and the operating cost of ultrafilter membranes in producing clean water. The findings of this review have a few industrial and policy implications. The outcomes of this review could be used by industrial engineers and consultants for designing the ultrafilter membrane system to optimize clean water production. The policy makers involved in technology selection for water filtration also can be used. The outcome of this study concludes that the ultrafilter membrane is an effective water treatment technology, but its performance depends on a few potential operating factors. This study recommends further research for optimizing the factors affect UFM performance in producing clean water.*

Keywords: Water sustainability, Ultra-Filter membrane, Sustainable Goal, Clean water, Production performance, Energy consumption, Water production cost

1.0 BACKGROUND OF THE STUDY

This paper aims to unlock the factors that affect the energy consumption and performance of ultrafiltration membranes (UFM) in producing clean water for achieving Sustainable Development Goal 6 (SDG 6). This study focuses on the operating parameters of plant machinery that affect the overall performance of UFM in producing the desired quality water. However, the UFM can divide into two groups, one based on molecular weight cut-off (MWCO) capability. Another one is the mode of water flow through the membrane (crossflow and dead-end flow)[1] [2]. The membrane filtration process is an advanced water treatment process that attracted attention because of its ease of operation, and maintenance requires small footprint installation and less time for project implementation, [2, 3]. Additionally, designing a UFM plant requires medium-level engineering skills, less energy consumption in plant operations, and minimum capital investment. A widespread application of UFM is limited by its poor performance in producing clean water. Various research in this field disclosed the factors responsible for the poor performance of the UFM. Research findings demonstrated that membrane fouling is a potentially identified factor that reduces performance. It was also reported that micro and macro particles, natural organic materials (NOM), suspended solids (TSS), and water-borne bacteria in feed water are the compositions of fouling. Fouling elements of feed water create a cake layer on the membrane and reduce pore size, [4]–[6]. To reduce the cake layer, pre-treatment for feed water is essential for removing fouling elements [7], [8]. The mode of UFM plant operation has appeared as a factor in achieving sustainable performance, which includes plant operating time and plant cleaning efficiency. All these factors are associated with energy consumption, plant maintenance frequency, the life cycle of UFM modules, and water production cost. Indeed optimizing all these factors could play a vital role in achieving the required performance [9], [10]. With this background, this study was conducted to reveal the optimum operating conditions of UFM to achieve sustainable performance by reducing energy consumption and the cost of plant operation for producing clean water at an affordable price.

2.0 MEASURING THE PERFORMANCE OF ULTRAFILEMEMBRANE

The UFM is a low-pressure driven system widely used in water treatment for potable water production, cooling water production for power plants, and process water production for food and chemical industries. Traditionally, this membrane has been installed at the secondary and tertiary levels in the water treatment process [11], [12]. Several indicators have been used for measuring the performance of UFM including permeate flux rate, efficiency in separating TSS and pollutant from feed water, energy consumption rate [kWh.(m^3-water)$^{-1}$], and productivity in clean water production [13]–[15]. The other potential indicators are the pollutant separation capability of UFM from water such as chemical oxygen demand (COD), biological oxygen demand (BOD), and water-born bacteria, [16]–[19].

2.1 Permeate Flux for Measuring the Performance of UFM

A few researchers have used the input-output water production model of the UFM, which presents by the equation (1).[16, 17, 20, 21].

$$J = K\frac{\Delta P}{t} \qquad \text{Eq (1)}$$

Here, J is the permeate flux. ΔP *is* the pressure difference across the membrane. "t" is the membrane thickness. K is the efficiency factor of UFM. Singh & Hankins, 2016 [20], and Ghidossi & Daorelle, 2006 [22] also used a similar model for measuring the performance of UFM.

A few researchers also used permeate flux for transmembrane pressure to measure the performance of UFM.

The cake layer on the membrane surface, the transmembrane pressure increases, which contributes to reducing permeate flux [1], [9]. Anis et al. [23], Giakoumis et al. [24], Weber et al. [25], Singh & Hankings [20], and Ramli & Bolong [18] demonstrate that pore size, the thickness of the membrane, and transmembrane pressure (TMP) have a significant role that affects the performance of UFM. A similar argument has been made by Karabelas & Sioutopoulos [26]. The permeate flux for the transmembrane pressure presents by the equation (**Error! Reference source not found.**2):

$$Jw = \frac{1}{A}\frac{dV}{dt} = \frac{[\Delta P]}{\mu[R_m + R_c]} \qquad \text{Eq (2)}$$

Here, Jw is permeate flux $(L.m^{-2}h^{-1})$. R_m is membrane resistance. R_c is cake resistance. Δp presents effective transmembrane pressure (TMP). μ is the viscosity of the feed water stream.

In this regard, Zirehpour & Rahimpour [16], Ramli & Bolong [18], and Yangang et al. [27] suggested that lower cake layer resistance can be achieved by keeping a high crossflow rate of backwash water through the membrane, which shears the cake layers form on the membrane surface. Additionally, Hong Tek [28] disclosed that the filtration efficiency increases with the operating pressure up to the optimum pressure level; but when the operating pressure goes higher than that level, the performance of the membrane starts to decrease [29].

2.2 Efficiency for Measuring the Performance of UFM

Zirehpour & Rahimpour [16], Ramli & Bolong [18], and Yangang et al. [27] have used efficiency (ŋ-water recovery in percentage) for measuring the performance of UFM in water production. The efficiency of the UFM can be estimaed by the the equation (3).

$$\text{Recovery}(ŋ\%) = \frac{\text{Permeate flow } (QP)}{\text{Feed flow } (Qf)} x\ 100 \qquad \text{Eq (3)}$$

2.3 Productivity for Measuring the Performance of UFM

Yangang et al. [27] and Wang et al. [19] have used productivity to measure the performance of membrane. Productivity is the permeate flux flow rate through the cross-sectional area of UFM. The productivity of UFM can be estimated by using the equation (4) [30].

$$\text{Membrane Productivity}(Jp) = \frac{Q(\frac{L}{h})}{Am} \qquad \text{Eq (4.0)}$$

Here, Jp is a productivity indicator. Qp stands for clean water output (litre per hour). Am expresses the surface area of the membrane in square meters (A^2). Lawrence et al. [31], and Ramli & Nurmin [17] have also used productivity to evaluate the performance of the UFM.

2.4 Energy Consumption for Measure the Performance of UFM

The energy consumption rate in producing clean water [kWh(m^3)$^{-1}$] was used to evaluate the performance of UFM. Saying et al. [32] and Ana et al. [33] undertook a pilot study to evaluate the performance of UFM with energy consumption concerning permeate flux [kWh(m^3)$^{-1}$]. Equation (5) can use for measuring the energy consumption rate of a UFM in water production.

$$P(\frac{kW}{m^3}) = \frac{QP}{ŋ_{pump}} \qquad \text{Eq (5)}$$

Here, P is the power used by pumps. Q (m^3h^{-1}) is the feed flow rate passing through the membrane at a pressure P in the bar. A series of research and development (R&D) activities has conducted to optimize the energy consumption performance [kWh(m3-water)$^{-1}$] in clean water production by UFM by reducing membrane resistance (TMP). The research findings demonstrate that the energy consumption rate in UFM is lower among the membrane family [33]–[36]. Additionally, the UFM system has distinguished as an economical, sustainable, and environmentally friendly water treatment process due to less energy consumption rate [22], [32], [37], [38]. A review in the section concludes that efficiency, productivity, and energy consumption rate per unit of water production are the indicators used to measure the performance of UFM.

3.0 FACTORS AFFECTING THE PERFORMANCE OF UFM

Factors related to the UFM system design and operation have used to evaluating performance; the potential factors are structure of UFM, feed water quality, and operating parameters. Pore size of UFM is an important part of membrane structure that plays a vital role in water production performance. The effect of paraments of feed water on permeate out have also used to measuring the performance of the UFM. The potential factors are total dissolved solids (TSS), pH, COD, BOD, feed water temperature, and water-born bacteria. The operating parameters of UFM also used to evaluating the performance, which are duration plant operations, feed water pressure, membrane backwash frequency, feed water flow rate, and process control devices.

3.1 Membrane Pore Size Affect Performance of UFM

The pore size (Ø) of UFM and the diameter of impurities are the essential factors that play a vital role in achieving UFM performance. The pore size (Ø) of UFM is between 0.004 to 0.45 µm. According to Zirehpour et al. [16], UFM has used to remove some impurities from a feed water stream. Especially , UFM is effective for removing TSS,NOM, and bacteria [16]. UFM is a porous media that has used to separate impurities from water by the molecular sieving process. For achieving require water quality, the pore size of the UFM shall be smaller than the diameter (d) of impurities.

3.2 Effects of Pre-treatment Efficiency on the Performance of Ultrafilter Membrane

A few researchers discovered that feed water pre-treatment efficiency is positively associated with the performance of UFM. It was reported that an efficient feed water pre-treatment is required to prevent cake layer formation, damaging membrane modules, and higher energy consumption [6], [39]–[41]. Bourgeous et al. [42], Carroll et al. [43], and Kabsch et al. [44] conducted experiments to investigate the effects of feed water pre-treatment on the fouling of UFM. The research finding of Carroll et al. [43] demonstrated that if the coagulation method is not effective for removing NOM from feed water requires to install some additional pre-treatment.. In this regard, a few researchers recommended installing series of pre-treatment such as sedimentation, aeration, media filtration, and microfiltration [45–48].

To address this issue, Bian et al. [49] and Shahidul et al. [50] have used PAC, and Kabsch et al. [44] used the ion exchange process. Additionally, Boltob et al. [51] and Humbert et al. [52] used anion exchange resin to remove NOM from the feed water. In this regard, Park et al. [53] and Choi et al. [54] used coagulation with low doses of coagulants to eliminate water turbidity and larger organic particles from feed water.

3.3 Effect of Feed Water TSS on the Performance of Ultrafilter Membrane

Falsanis et al. [55] and Illueca et al. [56] discovered that TSS in feed water is positively associated with the fouling formation rate in UFM and the overall performance of the membrane. The research report demonstrated that cake layer thickness in the membrane increases with the TSS of feed water and clogs the membrane pores resulting in increasing the resistance to water flow. The conclusion of the research reports is that permeated flux decreases with higher TSS. Additionally, overcoming resistance requires a high-pressure pump, which consumes energy and increases the operating cost of UFM. To address this issue, Bourgeois et al. [42], Kabsch-Korbutowicz et al. [44], and Carroll et al. [43] have used feed water pre-treatment and a chemically enhanced clean system of UFM.

3.4 Effect of Cake Layer Formation on the Performance of Ultrafilter Membrane

Particles of the feed water are transported through the feed stream to the membrane and create a cake layer on the membrane surface [16]. Blatt et al. [57], Yu et al., 2020 [36], and Koseoglu et al. [58] disclosed that the cake layer directly affects permeate flux, which reduces the overall performance of UFM. The effect of the cake layer on permeate flux can measure by the equation (6).

$$J_w = -k_d ln \frac{C_m+C_p}{C_b+C_p} \qquad \text{Eq (6)}$$

Here; C_b is the solids concentration of water (kg/m^3). C_m is the solids concentration on the membrane surface deposited from water (kg/m^3). C_p is the sides concentration of permeate (kg/m^3, g/L). $\mathrm{k_d}$ is the mass transfer coefficient through the membrane.

The productivity and reliability of membrane operations in producing clean water depend on the thickness of the cake layer. A few parameters are responsible for cake layer formation: NOM, TSS, turbidity, membrane pore size, pore size distribution in membrane surface, surface characteristics, and material of membranes [59], [60]. The mechanism of cake layer formation is present in Figure 1.

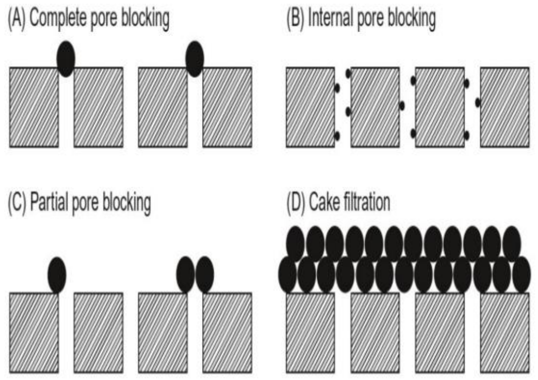

Figure 1: Fouling Mechanisms on Porous Membrane

(A) Complete pore blocking. (B) Internal pore blocking. (C) Partial pore blocking. (D) Cake filtration.

By operating an efficient pre-treatment for feed water, the parameters responsible for the cake layer can eliminate and thus such problem could be solved [59–61].

3.5 Effect of Water-Born Bacteria on the Performance of Ultrafilter Membrane

A higher concentration of water-borne bacteria in the feed water stream affects the overall performance. The bacteria of feed water create a biofilm on the membrane surface and make resistance to water flow and resulting in reduced permeate flux and increases energy consumption rate [kWh(m3-water)-1]. Dialynas & Diamadopoulos [43], Arévalo et al. [44], and Gómez et al. [45] discovered that the UFM is an effective means for removing bacteria. They found that the mean values of total coliform removal by UFM varied from 4.54 to 5.92 log (from 99.99715% to 99.99988%) [62]–[64]. However, they suggested eliminating water-borne bacteria from feed water to utilize the capacity of UFM. In this regard, Collivignarelli et al. [65] and Jamalinezhad et al. [15] reported that the installation of disinfection facilities in feed water is an effective means of reducing this problem [15], [65].

3.6 Effect of Feed Water pH on the Performance of Ultrafiler Membrane

A few experiments discovered that feed water with lower pH played a vital role in UFM performance. For example. Gao et al. [66] iinvestigated the effect of pH on membrane fouling. The findings demonstrated that pH reduction in feed water could decrease the molecular size of NOM and enhance the adsorption onto the membrane. This process contributes to reduce a significant level of fouling in membrane. Yitian et al. [67] revealed that feed water pre-treatment with coagulation at the low pH enhanced NOM removal efficiency from feed water, which mitigates the fouling effect. Dong et al. [68], Yitian et al. [67], and Due et al. [69] concluded that fouling could occur at a lower feed water pH, causing a decrease in the permeate yield. Furthermore, Wei et al. [70] and Bogati [71] disclosed that when UFM operates with low-pH feed water, the cake-layer formation rate increases, which contributes to increased energy consumption and operating costs. The authors conclude that low pH ($pH \leq 5.0$) water is responsible for poor membrane performance.

3.7 Effect of Membrane Cleaning on the Ultrafilter Membrane Performance

The membrane cleaning aims to restore adequate permeate flux. Falsanisi et al.[55]. and Xu *et al.* [72] rrevealed that the backwash period has a significant (p-value<0.05) effect on the removal of the cake layer accumulated on the membrane surface [55], [73]. In this aspect, Arévalo et al. [63] found that membrane-cleaning by backwash water and chemicals have a significant effect on reducing the cake layer that formed due to water-borne bacteria bio-film) and NOM [63]. Want et al., 2016 [74], Shi et al. [74], and Levitsky et al. [75] stated that membrane cleaning is a process whereby deposited substances remove from the membrane. The UFM cleaning can perform biologically, chemically, and physically. Nguyen & Roddick [76] and Levitsky et al. [75] pointed out that the effective ways to clean UFM are backwash (BW) with clean water and chemically enhanced backwash (CEB). The effect of membrane cleaning by BW and CEB is present in Figure 2 [21], [76], [77].

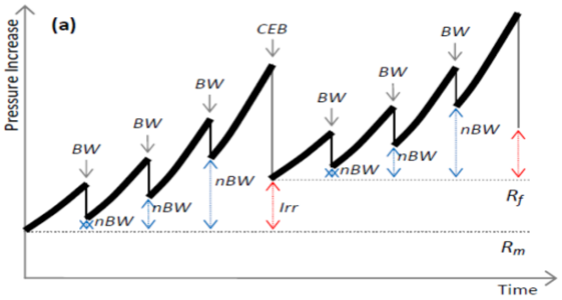

Figure 2: Effect of backwash on UFM cleaning Performance[21]

Figure 2 demonstrates the effect of backwash by water (BW) and chemically enhanced backwash (CEB), which indicates that the impact of CEB in membrane cleaning is much higher than that of BW.

3.8 Effect of Transmembrane Pressure on UFM Performance

According to Rosdianah & Nurmin, [17], the transmembrane pressure (TMP) is a scale used to measure the driving pressure required to push the water through the membrane pore. TMP has an impact on the permeate flux, and the value of TMP depends on the cake layer thickness. The feed water pre-treatment performance affects cake layer thickness. However, TMP can estimate by the equation (7) [78].

$$TMP = \frac{P_f + P_c}{2.0} - P_p \qquad \text{Eq (7)}$$

Here, the measurement unit of TMP is kPa or psi, P_p is permeate pressure (kPa in psi), P_f is feed water pressure (kPa in psi, $and\ P_c$ is concentrate pressure (kPa in psi). Rosdianah & Nurmin, [17], Li et al., 2018 [79], and Xia et al. [80] discovered that permeate flux is increased with TMP up to the optimum level, and after that, the permeate flux start to decline. A few researches have established a relationship between TMP and energy consumption; and demonstrated that at higher TMP, the energy consumption rate increase [kWh(m3-water)$^{-1}$] [81]–[84]. The conclusion of theses researches is TMP affect membrane the performance of UFM.

3.9 Effect of Feed Water Pressure on Water Production Performance of Ultrafilter Membrane

A few reports demonstrated that feed water pressure is a factor that affects the performance of UFM. Vishali & Kavitha [85] observed that feed water pressure influences the water production performance of UFM[85], [86]. Figure 3 presents the effect of feed pressure on the permeate flux of the UFM.

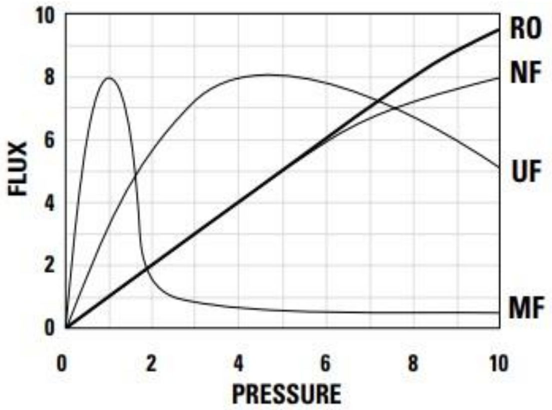

Figure 3: The effect of feed pressure on permeate flux of UFM [21].

Figure 3 demonstrates that permeate flux increases with feed water pressure, and after attaining optimum value, permeate flux starts to reduce. In some similar studies, Lise et al. [33]; Azmi et al [87, and Tansel et al. [88] revealed that permeate flux increases with feed pressure up to the optimum level. Research reports also demonstrated that the effect of feed water pressure on TDS separation by UFM is insignificant (p-value > 0.05). But, the TSS separation appeared to be significantly higher (p-value ≤ 0.05)[89], [90]. Moreover, it was disclosed by Yunos et al. [91], and Wu et al. [92] that the permeate flux of UFM increased to an optimum level with an identified certain feed pressure[87, 92]. These findings suggested that feed pressure affects the performance of UFM.

3.10 Effect of Operating Time on Permeate Flux of Ultrafilter Membrane

Wang et al. [19], Kumar et al. [93], and Beckmann et al. [38] discovered that the operating hour of UFM has an effect on permeate flux, cake layer thickness, TMP, and energy consumption. Russel & Kumar [94] have conducted experiments with UFM; Figure 4 presents the findings of this experiment. Figure 4 shows that the permeate flux decreases with operating time (≥30 minutes) of UFM.

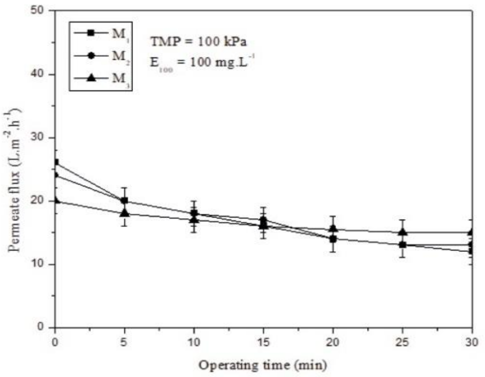

Figure 4: Effect of Operating Time on Flux. Kumar et al. [91]

In this regard, Myung et al. [95] and Ganesh et al. [88] also conducted experiments; and reported that cake layer thickness depends on plant operating time [21]. Beckmann et al., [20] conducted a similar research and revealed that energy consumption in UFM increased gradually with plant operating time. The conclusion of this research stated that the longer operating time of a UFM without BW and CEB affects its performance.

3.11 Effect of Feed Water COD on the Performance of Ultrafilter Membrane

Falsanisi et al. [55], Melgarejo et al. [96], and Nader & Bastaki [97] and Nader & Bastaki [97] have conducted experiments to investigate the effect of COD concentration of feed water on the performance of UFM. The findings demonstrate that a part of feed water COD deposited on the membrane surface and formed a cake layer. These deposited COD contributes to the pores clogging of the UFM. The effect of blocking pores are increasing the TMP, energy consumption, and reduction of permeate flux.

Kitanoua et al. [98] and Aditya et al. [99] have conducted a similar experiment and found that the COD influenced to increase TMP and to reduce permeate flux. They also reported that feed water COD is associated with the higher rate of cake layer formation and energy consumption [95].

Mutamim et al. [100] and Yang (2013) discovered that cake layer formation rate and yield of permeate flux of UFM depend on the concentration of feed water COD[100], [101]. To address the effects of COD on the performance reduction of UFM, a few research findings suggested installing an effective feed water pre-treatment with a multimedia granular filter and micron filter[55, 96, 97]. Studies conclude that the concentration of COD in feed water affects the performance of UFM on permeate yield and energy consumption rate [kW(m3)$^{-1}$].

3.12 Effect of Feed Water Temperature on the Performance of UFM

Xu et al. [72], and Praneeth et al. [102] have conducted experiments to evaluate the effect of feed water temperature on permeate flux. Research reports disclosed that permeate flux dropped by 20% for feed water temperature reduced from 30 to 18˚C.Reports of similar experiments conducted by Shengji et al. [103] and Benítez et al. [104] revealed that the high temperature of feed water does not necessarily increase the permeate flux. In this regard, Shengji et al. [80] discovered that at the feed water temperature of less than 20˚C, the water molecules contain a minimum amount of energy and decrease their velocity. Due to that, the water molecules lost their ability to pass through the membrane layer. These studies conclude that lower feed water temperature (≤20˚C) affects the permeate flux.

3.13 Effect of BOD on Ultrafilter Membrane's Performance

Azmi et al. [91] discovered that BOD concentration in the feed stream affects the performance of UFM. The research findings demonstrate that the BOD removal efficiency of UFM could be 90%, and a part of BOD could deposit on the membrane surface. The study report disclosed that the deposited BOD is responsible for cake layer formation on the membrane surface. Jack [105] and Azmi et al. [91]. And Shahidul et al. [106] experimented with biomass-enriched feed water. The have conducted similar experiments with biomass-enriched feed water and discovered that biomass in feed water are responsible for BOD, which contributes to form cake layer in membrane surface. Studies conclude that the concentration of BOD in feed water affects the performance of UFM.

3.14 Effect of Process Control System on the Performance of Ultrafilter Membrane

Paulen & Fikar [105], Bernhard & Uwe [106], Bernhard & Uwe [101] and Huang et al. [109] discovered the impact of the process control device on the performance of UFM. The reports demonstrated that the process control device in the UFM system was proven to be successful in monitoring and controlling the limit of TSS, bacteria, colloidal particles, and turbidity in product water. The process control device also contributed to optimizing permeate flux and energy consumption to some extent. Huang et al [109] stated that the process control system in the UFM plant was an effective tool for eliminating bacteria, colloid materials, suspended particles, turbidity, and a portion of total organic carbon from the feed water**.** Appels et al., 2011 [34] installed a process control device in the UFM plant to optimize permeate flux and energy consumption rate by controlling the factors that affect the performance.

A few researchers also used process control system in optimizing the permeate flux, energy consumption, and operating cost [33, 110, 111] Research findings concluded that a real-time monitoring technology is an effective process control device in tracking colloidal particles, nanoparticles concentration in the feed water to reduce the cake layer on the UFM surface. Thus, a real-time monitoring process control device has appeared to be an effective tool in UFM plant operations in optimizing permeate lux, energy consumption, and operating cost.

3.15 Effect of UFM Operating Parameters on Energy Consumption

Ghidossi et al [22] conducted an experiment with the UFM plant to develop an energy consumption model. Findings demonstrated that UFM required energy for feed water pump operations for producing clean water and to operate backwash water supply pumps. It was also reported that the energy consumption of UFM depends on the efficiency of the feed water treatment plant and maintenance of the UFM [32], [33]. Aditya et al. [10], Chang et al. [112], and Chon et al. [2] have conducted experiments with water pre-treatment by utilizing macro and microfiltration for removing TSS, NOM, BOD, and COD from water stream and discovered that rate of cake layer formation on membrane reduced significantly with energy consumption rate 1.0 kWh(m3)$^{-1}$ [29].

3.16 Factors Affects the Operating Cost of Ultrafilter Membrane

Samaco [1] and Nguyen et al. [110] revealed the operating cost of UFM in producing clean water from a feed water stream. According to their research findings, operating cost depends on a few primary factors, such as energy consumption rate [kWh(m3)$^{-1}$] of pumps, chemicals used for membrane cleaning, and plant maintenance performance. Aditya et al. [97], Chang et al. [112], and Chon et al. [2] have conducted research for the optimization of UFM plant operating costs. Research findings suggested installing an efficient pre-treatment to reducing operating costs. Nguyen et al. [113], Yoo et al. [3] and Sung [9] and Jamalinezhad et al. [14] have conducted similar experiments and discovered that the operating cost depends on the factors affecting the performance of UFM, and the optimum level cost would be about 11.2% of the total water production cost.

4.0 FINDINGS OF LITERATURE REVIEW AND CONCLUSION

This paper reports a study on factors that affects the performance of UFM in producing clean water from the feed stream. This study was designed to unlock the influence of efficiency, productivity on energy consumption and operating costs in producing clean water by UFM.

This study revealed that the overall performance of UFM has been measured with efficiency, productivity, energy consumption rate in clean water production [kWh(m3)$^{-1}$], and the cost of water production per litre. Study also revealed that the performance of UFM also depends on feed water pressure, duration of plant operation, and the pore size of the membrane. Furthermore, various research reports demonstrate that a few potential factors highly affect the performance of UFM. The factors are the effectiveness of pre-treatment, the concentration of TSS, COD, BOD, and particulates of NOM in the feed water, the thickness of the cake layer developed on the membrane surface, feed water pressure, feed water flow rate, pH of feed water and membrane backwash efficiency. The research findings are summarized and listed in Table 1, Table 2 and Table 3.

Table 1: Research Findings

	Research Finding
1.0	Poor feed water quality, which commonly expressed as high TSS, BOD, COD, NOM, and water-borne bacteria, are responsible for formation of a cake layer on the membrane surface. These factors affect energy consumption and water production cost. This problem was addressed by install an efficient pre-treatment with an aeration, macro, and microfiltration system.
2.0	The chemical-enhanced membrane cleaning and backwash with clean water have been used to reduce the cake thickness in the membrane. These steps contribute to reducing energy consumption rate in water production.
3.0	Though at higher feed water temperatures (≥ 30ºC) membrane is thermally stable, but at low-temperature (20ºC ≤) affects permeate flux of UFM. Permeate flux could be reduced by 20% for a feed water temperature less than 18˚C
4.0	The process control device in the UFM plant appeared to be effective in monitoring and controlling the limit of TSS, bacteria, colloidal particles, and turbidity in product water. The process control device also appeared as an effective means for optimizing permeate flux and energy consumption.
5.0	This study revealed that once membrane fouling occurs, it reduces permeate flux, productivity, and lifespan of the membrane modules and increases system downtime, membrane maintenance, and operation costs.

Table 2: Performance Measuring Indicators of UFM

Indicators	References
Efficiency	Rajindar(2015), Singh(2015), Jamalinezhad et al.(2020), et al.(2020), Zirehpour, A., Rahimpour (2016), Ramali, R., Bolong (2016), Ghidossi (2006), Yangang et al.(2022), Hong (2021), Li.(2022), Ana etal.(2020), Lise et al.(2011), Xiao et al.(2012),Yu et al.(2020), Razak et al.(2015), Broeckmann,et al.(2015).
Productivity	Ghidossi et al.(2006), Wang et al.(2021),Shahidul et al.(2011), Lawrence et al.(2011), Ramli & Bolong (2016).
Permeate Flux	Samco (2015), Sung (2018), Anis et al.(2019), Giakoumis et al.(2020), Weber et al.(2019), Singh & Hankins((2006), Ramali & Bolong(2016), Karabelas & Sioutopoulos (2014).
Energy Consumption	Ghidossi et al.(2006), Yu et al.(2020), Ana et al.(2020), Lise et al.(2011) Pé,(2012), Chang et al.(2019). Xia0 et al.(2012), Broeckmann et al.(2006), Razak et al.(2015).

Table 3a: Factor Affect the Performance of UFM

Factors Affecting Performance	References
Structure of UFM	Zirehpour & Rahimpour (2016), Giakoumis et al.(2020),
Feedwater pre-treatment performance	Lic & Cheny (2004), Tomaszewska & Moiza (2002). Mozia et al.(2005), Klomaas & Koniecznny (2004), Bourgeous et al.(2001), Carroll et al.(2000), Kabsch-Korbutowicz et al.(2006), Choik & Dempseyb (2004), Leiknes et al.(2004), Judd & Hillis (2004), Oh & Seock(2005).
TSS in Feedwater	Bourgeous et al.(2001), Carroll et al.(2000), Kabsch-Korbutowicz et al.(2006), Falsanisi et al.(2010), et al.(2005), Illueca-Muñoz et al.(2008).
Cake Layer Formation in UFM	Zirehpour & Rahimpour (2016), Blatt et al.(1970), Yu et al.(2020), Koseoglu et al.(2018), Cui et al.(2018), Jadhao & Dawande (2018).
Water-Born Bacteria	Jamalinezhad et al.(2020), Kabsch-Korbutowicz et al.(2006), Choik & Dempseyb (2004), Leiknes et al.(2004), Dialynas & Diamadopoulos(2008), Arévalo, et al.(2009), Arévalo et al.(2004), Collivignarelli et al.(2018).
Feedwater pH	Gao et al.(2006), He et al.(2022), Du et al.(20020).
Transmembrane Pressure	Ramli & Bolong (2016), Lanxess (2013), Xiangmin et al.(2018), Xiaoyan et al.(2009), Steinhauer et al.(2015), Researd Baker (2004), Maryna et al.(2011).

Table 3b: Factor Affect the Performance of UFM

Membrane cleaning Performance	Xu et al.(2016), Hongbin et al.(2019), Arévalo et al.(2009), Want et al.(2016), Arévalo et al.(2012), Nguyen & Roddick (2011), Ferrer et al.(2016).
COD in Feed water	Falsanisi et al.(2010), Melgarejo,et al.(2016), Nader & Bastaki(2004), Kitanoua et al.(2019), Aditya et al.(2020), Mutamim et al.(2012), Myung et al.(2001), Yang (2013).
Feed water Pressure	Lise et al.(2011), Vishali & Kavitha(201), Jørgen (2001). Azmi et al.(2013), Tansel,et al.(2017), Wahab et al.(2012), Shuji & Alan(1992), Wu et al.(2007).
Operating time	Wang et al.(2021), Kumar et al.(2017), Russell and Kumar (2017), Myung et al.(2001), Shuji & Alan (1992).
BOD in Feed water	Azmi et al.(2013), Shahidul (2018), Jack(2006).
Process Control System	Paulen & Fikar (2016), Bernhard & Uwe (2021), Shengji et al.(2007), Huang et al.(2009), Tonni et al.(2021), Gilabert(2009), Olsson et al.(2005), Ganesh et al.(2021), Ana et al.(2020).
Energy Consumption	Ghidossi et al.(2006), Li et al.(2022), Ana et al.(2020), Chon et al.(2012), Porcelli & Suddy(2010), Pé,(2012), Chang et al.(2019).
Operating Cost	Nguyen et al.(2015), Samco (2017), Aditya et al.(2020), Chang et al.(2019), Chon et al.(2012).

4.1 Implication of Research Findings

The findings have a few implications in water industry and policy making domain.

a) Clean water production from wastewater, saline water and river water is a difficult task. In these fields, UFM could play a vital role by making water treatment easier. The information gather through this literature review on UFM operations and maintenance can be utilized for optimizing UFM design and operations. The information listed in this finding of literature could be also used for optimizing performance of UFM in clean water production.

b) Water is an essential input in the economic activities and daily life affairs. In this regard, effective strategy for clean water production from run-off water and wastewater by using UFM can play a vital role. The literature findings on UFM listed in this paper could be a source of information in develop an effective strategy.

This review concludes that further research is required to develop a model to optimize factors that affect the performance of UFM in producing and supplying clean water at the minimum energy and affordable cost. This article would be a reference for further research on developing an effective UFM plant to produce clean water for achieving a sustainable water supply (SDG 6).

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6.0 REFERENCES

1. SAMCO; Editor, "How Much Do Microfiltration and Ultrafiltration Membrane Systems Cost," *SAMCO*, 2017. https://samcotech.com/how-much-do-microfiltration-and-ultrafiltration-membrane-systems-cost/.
2. Chon K;Kim SJ; Moon J; Cho J., "Combined coagulation-disk filtration process as a pretreatment of ultrafiltration and reverse osmosis membrane for wastewater reclamation: an autopsy study of a pilot plant," *Water Res.*, vol. 46, no. 6, pp. 1803–1816, 2012.
3. Yoo S.S; Chu K.H;Choi I.H;Mang J.S; Ko K.B, "Operating cost reduction of uf membrane filtration process for drinking water treatment attributed to chemical cleaning optimization," *J. Environ. Manag*, vol. 206, pp. 1126–1134, 2018.
4. Kimura, K., Hane, Y., Watanabe, Y., Amy, G., Ohkuma, N., "Irreversible membrane fouling during ultrafiltration of surface water," *Water Res.*, vol. 38, no. 3431, 2004.
5. Lee, N., Amy, G., Croue .J., Buisson, H., "Identification and understanding of fouling in low-pressure membrane (MF/UF) filtration by natural organic matter," *Water Res.*, vol. 38, no. 4511, 2004.
6. Li, C., Chen, Y., "Fouling of UF membrane by humic substance: effect of molecular weight and power activated carbon (PAC) pre-treatment," *Desalination*, vol. 170, no. 59, 2004.
7. Yamamura H.; Kimura K.; Watanabe Y., "Mechanism involved in the evolution of physically irreversible fouling in microfiltration and ultrafiltration membranes used for drinking water treatment," *Environ. Sci. Technol*, vol. 41, pp. 6789–6794, 2007.
8. Haiou Huang, Kellogg Schwab, Joseph, G., "Pretreatment for low pressure membranes in water treatment: A Review," *Sci. Technol*, vol. 43, pp. 3011–3019, 2009.
9. Sung Soo Yoo, "Operating Cost Reduction of In-line Coagulation/Ultrafiltration Membrane Process Attributed to Coagulation Condition Optimization for Irreversible Fouling Control," *Water*, vol. 10, no. 8, 2018.
10. Porcelli N.;Suddy S., "Chemical cleaning of potable water membranes: the cost benefit of optimisation," *Water Res.*, vol. 44, pp. 1389–1398, 2010.
11. Shahidul M.I; Lee. M, "Determinants of desalination machinery capacity utilization: evaluate in the aspect of energy, Enviromnet and Economic Sustainability," *Eng. Conf.*, 2014.
12. Guo Y.; Liang H.; Bai L.; Huang K.; Xie B.; Xu D.; Wang J.;Li G.;Tang X., "Application of heat-activated peroxydisulfate pre-oxidation for degrading contaminants and mitigating ultrafiltration membrane fouling in the natural surface water treatment," *Water Res.*, vol. 179, 2020.
13. Rajindar S., "Design, Energy and Cost Analyses of Membrane Processes," in *Membrane Technology and Engineering for Water Purification*, S. Edition, Ed. 2015, pp. 339–368.
14. Singh R., *Membrane Technology and Engineering for Water Purification*. ScinceDirect, 2015.
15. Jamalinezhad M.;Hassani A.H.; Borghei M.; Amin M.M, "Performance evaluation of filtration and ultrafiltration for municipal secondary effluent reuse," *Glob. NEST J.*, vol. 22, no. 2, pp. 431–437, 2020.
16. Zirehpour, A., Rahimpour, A., *Membranes for Wastewater Treatment*, vol. 2, no. September. 2016.
17. Ramli, R., Bolong, N., "Effects of pressure and temperature on ultrafiltration hollow fiber membrane in mobile water treatment system," *J. Eng. Sci. Technol.*, vol. 11, no. 7, pp. 1031–1040, 2016.
18. Ramali, R., Bolong, N., "Effects of Pressure And Temperature on Ultrafiltration Hollow Fiber Membrane in Mobile Water Treatment System," *J. Eng. Sci. Technol.*, vol. 11, no. 7, pp. 1031–1040, 2016.
19. Wang, Q.; Peng, Y.; Ji, X.; Hadi, M.K.; Zhang, S.; Tang, J., Ran, F., "Conductive 3D networks in a 2D layer for high performance ultrafiltration membrane with high flux-retention and robust cyclic stability," *J. Membr. Sci*, vol. 640, 2021.
20. Singh, R., Hankins, N.P., "Introduction to Membrane Processes for Water Treatment," in *Emerging Membrane Technology for Sustainable Water Treatment*, 2016, pp. 15–52.
21. Shahidul, M.I., Michael, A.B., "Factors Affect Clean Water Production Performance: A Review on Ultrafiltration Membrane," *Sci. Int.(Lahore)*, vol. 34, no. 6, pp. 537–544, 2022.
22. Ghidossi, R., Daurelle, R.,Veyret, D., Moulin, P., "Simplified CFD approach of a hollow fiber ultrafiltration system," *Chem Engeering J.*, vol. 123, no. 3, pp. 117–125, 2006.
23. Anis, S., Hashaikeh, R., Hilal, N., "Microfiltration membrane processes: A review of research trends over the past decade," *J. Water Process Eng.*, 2019, https://doi.org/10.1016/j.jwpe.2019.100941.
24. Giakoumis,T.,Vaghela, C., Voulvoulis, N., "The role of water reuse in the circular economy," in *Advances in Chemical Pollution, Environmental Management and Protection*, 2020, pp. 227–252.
25. Weber,M., Julbe, A.,Kim, S.S., Bechelany, M., "Atomic layer deposition (ALD) on inorganic or polymeric membranes," *J. Appl. Phys.*, vol. 126, no. 041101, 2019.
26. Karabelas, A. J.,Sioutopoulos, D. C., "Toward improvement of methods for predicting fouling of desalination membranes: The effect of permeate flux on specific fouling resistance," *Desalination*, vol. 343, pp. 97–105, 2014, https://doi.org/10.1016/j.desal.2013.10.008.
27. Yangang, Z., Zhangfu,Y., Bai ,H., Zhao,L., Chunhong,S., "A Pilot-Scale Treatment of Steel Plant Wastewater by PVDF Hollow Fiber Ultrafiltration Membrane with Low Packing Density," *Seperation*, vol. 9, no. 37, pp. 1–14, 2022.
28. Hong Tek, "How to Improve the Water Yield of UF Membrane Modules?," 2021.

https://www.hongtekfiltration.com/news/improve-water-yield-of-uf-membrane-modules.html.

29. Pé, L. Z., "Evaluation of High Pressure Effects on Ultrafiltration Process Applied to Aqueous Inkjet Colorant," Instituto Superior Técnico, 2012.

30. Shahidul, M.I., Syed Shazali,S.T., Azrin, M.H.S., "Determinants of Manufacturing Productivity : A Pilot Study on Labor Intensive Industries," *Int. J. Product. Perform. Manag.*, vol. 60, no. 6, pp. 567–582, 2011.

31. Lawrence,K., Wang,J., Chen,P.I., Hung,Y., Shammas, N.K., *Membrane and Desalination Technologies*, 1st ed. Humana Totowa, NJ, 2011.

32. Li, S., Milia, M., Schäfer, A., Richards, B., "Renewable energy powered membrane technology: Energy consumption analysis of ultrafiltration backwash configurations," *Sep. Purif. Technol.*, vol. 287, no. 120388, 2022.

33. Avilés, A., Velázquez, F., and del Riquelme, M., "Methodology for Energy Optimization in Wastewater Treatment Plants. Phase III: Implementation of an Integral Control System for the Aeration Stage in the Biological Process of Activated Sludge and the Membrane Biological Reactor," *Sens. MDPI*, vol. 20, no. 15, p. 4342, 2020.

34. Lise, A., Joost, L., Jan, D., Lieve, H., Bart, L., Kris, W., Jan, V.I., Raf, D., "Anaerobic digestion in global bio-energy production: Potential and research challenges," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4295–4301, 2011, https://doi.org/10.1016/j.rser.2011.07.121.

35. Xiao, F., Xiao, D.S., Wang, D., Qin, T., He ,S., "Investigation of organic foulants behavior on hollow-fiber UF membranes in a drinking water treatment plant. Separation and Purification Technology," *Org. foulants Behav. hollow-fiber UF Membr. a Drink. water Treat. plant. Sep. Purif. Technol.*, vol. 95, pp. 109–117, 2012.

36. Yu, H., Li , X., Chang, H., Zhou, Z., Zhang, T., Yang, Y., Li, G., Ji, H., Cai, C., Liang ,H., "Performance of hollow fiber ultrafiltration membrane in a full-scale drinking water treatment plant in China: A systematic evaluation during 7-year operation," *J. Memb. Sci.*, vol. 613, no. 118469, 2020.

37. Razak, N., Praveena, S., Aris, A., Hashim, Z., "Drinking water studies: A review on heavy metal, application of biomarker and health risk assessment (a special focus in Malaysia)," *J. Epidemiol. Glob. Health*, vol. 5, no. 4, pp. 297–310, 2015.

38. Broeckmann, A., Busch, J., Wintgens,T.,Marquardt,W., "Modeling of pore blocking and cake layer formation in membrane filtration for wastewater treatment," *Desalination*, vol. 189, no. 1–3, pp. 97–109, 2006.

39. Tomaszewska, M., Moiza. S., "Removal of organic mat¬ter from water by PAC/UF system," *Desalination*, vol. 36, no. 4137, 2002.

40. Mozia, S., Tomaszewska, M., Morawski, A., "Studies on the effect of humic acids and phenol on adsorption-ultrafiltration process performance," *Water Res.*, vol. 39, no. 501, 2005.

41. Klomaas, G., Konieczny, K., "Fouling phenomena in unit and hybrid processes for potable water treatment," *Desalination*, vol. 163, no. 311, 2004.

42. Bourgeous, K.N., Darby, J.L., Tchobanoglous, G., "Ultrafiltration of wastewater: Effects of particles, mode of operation, and backwash effectiveness," *Water Resour. Manag.*, vol. 35, no. 1, pp. 77–90, 2001.

43. Carroll, T., King, S., Grays, R., Boltoba, A., Book-Ern, A., "The fouling of microfiltration membranes by NOM after coagulation treatment," *water Res.*, vol. 34, no. 2861, 2000.

44. Kabsch-Korbutowicz, M., Biłyk, A., Mołczan, M., "The Effect of Feed Water Pretreatment on Ultrafiltration Membrane Performance," *Polish J. Env.*, vol. 15, no. 5, pp. 719–725, 2006.

45. Choik.Y., Dempseyb, A., "In-line-coagulation with low-pressure membrane filtration," *Water Res.*, vol. 38, no. 4271, 2004.

46. Leiknes, T., Ødegaard, H., Myklebust, H., "Removal of natural organic matter (NOM) in drinking water treatment by coagulation-microfiltration using metal membranes," *J. Memb. Sci.*, vol. 242, no. 47, 2004.

47. Judd, S., Hillis, P., "Optimisation of combined coagulation and microfiltration for water treatment," *Water Res.*, vol. 35, no. 2895, 2004.

48. Oh, J.,Seock, H., "Influence of streaming potential on flux decline of microfiltration with in-line rapid pre-coagulation process for drinking water production," *J. Memb. Sci.*, vol. 254, no. 39, 2005.

49. Bian, R., Watanabe, Y., Ozawa , G., Tambo, N., "Membrane fouling of ultrafiltration: evaluation of influence of pretreatment with batch test," *J. Japan Water Work. Assoc*, vol. 67, no. 11, 1998.

50. Shahidul, I., Ting, C., Lee, M., Shahnur, Begum, S., "Seawater Desalination for Environment and Economic Sustainability: A Case Study at Sadong Jaya Pilot Plant," *Int. J. Eng. Res. Manag.*, vol. 2, no. 8, pp. 69–74, 2015.

51. Bolto,B.,Dixon, D., Eeldridge, R, King,S., LIing, K., "Removal of natural organic matter by ion exchange," *Water Res.*, vol. 36, no. 5057, 2002.

52. Anderon, C., Maier, W., "Trace organics removal by anion exchange resins," *Water Res.*, vol. 39, no. 1699, 2005.

53. Wang, N.A., Jun,M.A., "Study of Adsorbability of the Colloidal Particles from Different Stages of a Conventional Water Treatment Plant," *Environ. Sci. Technol*, vol. 40, pp. 2699–2705, 2006.

54. Choi, Y.H., Kim, H.S., Kweon, J.H., "Role of hydrophobic natural organic matter flocs on the fouling in coagulation-membrane processes," *Sep. Purif. Technol*, vol. 62, pp. 529–534, 2008.

55. Falsanisi,D.,Liberthi.,L., Notarnicola, M., "Ultrafiltration (UF) Pilot Plant for Municipal Wastewater Reuse in Agriculture: Impact of the Operation Mode on Process Performance," *Water*, vol. 2, no. 4, pp. 872–885, 2010.

56. Illueca-Muñoz, J., Mendoza-Roca, A., Iborra-Clar, A., Bes-Pia, A., Fajardo-Montañana, V., Martinez-Francisco, F., Bernácer-Bonora, I., "Study of different alternatives of tertiary treatments for wastewater reclamation to optimize the water quality for irrigation reuse," *Desalination*, vol. 222, no. 1–3, pp. 222–229, 2008.

57. Blatt, W., Dravid, A., Michaels, A. and Nelsen, I., "Solute Polarization and Cake Formation in Membrane Ultrafiltration: Causes, Consequences, and Control Techniques," *Membr. Sci. Technol.*, pp. 47–97, 1970, https://doi.org/10.1007/978-1-4684-1851-4_4.

58. Koseoglu, H., Guler, E., Harman, B. and E. Gonulsuz, *Water flux and reverse salt flux*. Elsevier B.V., 2018.

59. Cui, Z. F., Jiang, Y.,Field, R. W., *Fundamentals of Pressure-Driven Membrane Separation Processes*, First Edit. Elsevier Ltd, 2010.

60. Jadhao, R., Dawande, S., "Reverse Osmosis and Ultrafiltration Membrane for Hospital Wastewater Treatment," *Int. J. Chem. Sci. Appl.*, vol. 3, no. 2, pp. 283–288, 2012.

61. Sen, R.T., Chai, T. O., "A simulation study of capacity utilization to predict future capacity for manufacturing system sustainability," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 109, no. 1, 2018, https://doi.org/10.1088/1755-1315/109/1/012020.

62. Dialynas, E., Diamadopoulos, E., "Integration of immersed membrane ultrafiltration with coagulation and activated carbon adsorption for advanced treatment of municipal wastewater," *Desalination*, vol. 230, no. 1–3, pp. 113–127, 2008.

63. Arévalo, J., Garralón, G., Plaza, F., Moreno, B., Pérez, J., Gómez, M.A., "Wastewater reuse after treatment by tertiary ultrafiltration and a membrane bioreactor (MBR): a comparative study," *Desalination*, vol. 243, no. 1–3, pp. 32–41, 2009.

64. Espinoza-Gómez, H., Lin, W. and Espinoza-Gómez, H., Rogel -Hernández, E., "Nanofiltration Membrane Pore Diameter Determination," *J. Mex. Chem. Soc.*, vol. 48, no. 1, pp. 15–20, 2004.

65. Collivignarelli, M., Abbà, A., Benigna, I., Sorlini , S., Torretta, V., "Overview of the Main Disinfection Processes for Wastewater and Drinking Water Treatment Plants," *Sustainability*, vol. 10, no. 1, pp. 1–21, 2018.

66. Gao, Z., Wang, L., Miao, R., Mi, N., Li, S., Zhu.M., "Effect of pH on UF membrane fouling of organic foulant (BSA)," *China Environ. Sci.*, vol. 35, no. 12, pp. 3640–3645, 2015.

67. He, Y., Huang, X., Li, T., Lv, X., Tang, N., Feng, C., Shi, B., "Ultrafiltration membrane fouling control by two-stage coagulant dosing with moderate pH adjustment," *Desaliantion*, vol. 537, no. 115899, 2022.

68. Gao, Z., Wong, L., Miao, R., Mi, N., Li, S., Zhu, M., "Effect of pH on UF membrane fouling," *Desaliantion*, vol. 195, no. 1–3, pp. 201–208, 2006.

69. Du, P., Li, X., Yang, Y., Fan, X., Fang, X., Zhou, Z., "Enhanced coagulation by two-stage alum addition: the role of solution pH, floc breakage and assistant of non-ionic polyacrylamide," *Enironment Technol.*, vol. 42, no. 28, pp. 4456–4465, 2020.

70. Wei, G., Heng, L., Jun,M., Mei, H., Zhong-lin,C., Zheng- Shuang, H., and Gui bai,L., "Membrane fouling control in ultrafiltration technology for drinking water production: A review," *Desalination*, vol. 272, no. 1–3. Elsevier, pp. 1–8, May 2011, https://doi.org/10.1016/j.desal.2011.01.051.

71. Bogati, R.C., "Membrane Fouling and Its Control in Drinking Water Membrane Filtration Process," Lakehead University, Canada, 2014.

72. Xu, J., BSingh, Y. LAmy, G.,Ghaffour, N., "Effect of operating parameters and membrane characteristics on air gap membrane distillation performance for the treatment of highly saline water," *J. Memb. Sci.*, vol. 512, pp. 73–82, 2016.

73. Hongbin, X., Japp, D.K., Yang, G., "Reliability and efficiency of an advanced tertiary treatment process for wastewater reclamation," *J. Water Reuse Desalin.*, vol. 9, no. 4, pp. 385–395, 2019.

74. Wang, C., Wei, A., Wu, H., Qu, F., Chen, W., Liang, H., Li, G., "Application of response surface methodology to the chemical cleaning process of ultrafiltration membrane," *Chinese J. Chem. Eng.*, vol. 1, no. 1, pp. 1–17, 2016.

75. Levvitsky, L., Naim, R., Duek, A., Gitus, V.A., "Cleaning of fouled ultrafiltration (UF) membrane by algae during reservoir water treatment," *Eff. Time Chem. Clean. Ultrafiltr. Membr.*, vol. 35, no. 5, pp. 941–946, 2012.

76. Nguyen, S.T., Roddick,F.A., "Chemical cleaning of ultrafiltration membrane fouled by an activated sludge effluent," *Desalin. Water Treat.*, vol. 34, no. 1, pp. 94–99, 2011.

77. Ferrer, O., Lefèvre, B., Prats, G., Bernat, X., Gibert, O., Paraira, M., "Reversibility of fouling on ultrafiltration membrane by backwashing and chemical cleaning: differences in organic fractions behavior," *Desalin. Water Treat.*, vol. 67, no. 1, pp. 8593–8607, 2016.

78. LANXESS Deutschland GmbH, "Principle of Reverse Osmosis Membrane Separation," *Desalination*, vol. 7, no. 2, pp. 1–9, 2013.

79. Xiangmin, L., Jiang, L., Haixiang, l., "Application of Ultrafiltration Technology in Water Treatment," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 186, no. 3, 2018, https://doi.org/10.1088/1755-1315/186/3/012009.

80. Shengji, X., Xing, L., Ruiping, L., and Guibai,L., "Study of reservoir water treatment by ultrafiltration for drinking water production," *Desalination*, vol. 167, no. 1–3, pp. 23–26, 2004, https://doi.org/10.1016/j.desal.2004.06.109.

81. Xiaoyan, G., Zhenjia, Z., Lin, F., and Liguo, S., "Study on ultrafiltration for surface water by a polyvinylchloride hollow fiber membrane," *Desalination*, vol. 238, no. 1–3, pp. 183–191, 2009, https://doi.org/10.1016/j.desal.2007.11.064.

82. Steinhauer, T., Lonfat, J., Hager, I., Gebhardt, R., Kulozik, U., "Effect of pH, transmembrane pressure and whey proteins on the properties of casein micelle deposit layers," *J. Memb. Sci.*, vol. 493, pp. 452–459, 2015.

83. Researd Baker, *Membrane Technology and Applications*, 2nd Editio. John Wiley & Sons, Inc, 2004.

84. Maryna, P., Jonas, M., Jacqueline ,T., Wouter, P., "Mechanisms of membrane fouling during ultra-low pressure ultrafiltration," *J. Memb. Sci.*, vol. 377, pp. 42–53, 2011.

85. Vishali, S. and Kavitha, E., "Application of membrane-based hybrid process on paint industry wastewater treatment," *Membr. Hybrid Process.*

Wastewater Treat., pp. 97–117, 2021, https://doi.org/10.1016/B978-0-12-823804-2.00016-1.

86. Jørgen, W., "Membrane Filtration Handbook Practical Tips and Hints," no. November, 2001.
87. Khairul, F.Y., Nurul, A.M., Nazli, M.N., Azhari, S.B., Rahman,A.H., "Ultrafiltration of palm oil mill effluent: Effects of operational pressure and stirring speed on performance and membranes fouling," *Environ. Eng. Res.*, vol. 24, no. 2, pp. 263–270, 2019.
88. Tansel,B., Dizge,N., Tansel, I.N., "Analysis of high resolution flux data to characterize fouling profiles of membranes with different MWCO under different filtration mode," *Seperation Purif. Technol.*, vol. 173, no. 1, pp. 200–208, 2017.
89. Wahab, A.M., Ching, Y.N., Ying, P.L., Gen, H.N., "Ultrafiltration in Food Processing Industry: Review on Application, Membrane Fouling, and Fouling Control," *Food Bioprocess Technol.*, vol. 5, pp. 1143–1156, 2012.
90. Shuji, N., Alan, S.M., "Transport and separation of proteins by ultrafiltration through sorptive and non-sorptive membranes," *J. Memb. Sci.*, vol. 69, no. 3, pp. 189–211, 1992.
91. Azmi, N.S., Yunos, K.F., Baharuddin, S.A., Dom, Z.M., "The effect of operating parameters on ultrafiltration and reverse osmosis of palm oil mill effluent for reclamation and reuse of water," *Bio Res.*, vol. 8, no. 1, pp. 76–87, 2013.
92. Wu, T.Y., Mohammad, A.W., Jahim,J.M., Anuar, N., "Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling," *Biochem. Eng. J.*, vol. 35, no. 3, pp. 309–317, 2007.
93. Kumar, S., B. K. Nandi, C. Guria, and Mandal, A., "Oil removal from produced water by ultrafiltration using polysulfone membrane," *Brazilian J. Chem. Eng.*, vol. 34, no. 2, pp. 583–596, 2017, https://doi.org/10.1590/0104-6632.20170342s20150500.
94. Russell, A., Kumar, B., "Forestry for a Low-Carbon Future: Integrating Forests and Wood Products Into Climate Change Strategies," *Environment*, vol. 59, no. 2, pp. 16–23, 2017, https://doi.org/10.1080/00139157.2017.1274580.
95. Myung, C., Gui-young, C., Jae-Jin, K., "On the behavior of the electrostatic colloidal interaction in the membrane filtration of latex suspensions," *J. Memb. Sci.*, vol. 193, pp. 97–109, 2001.
96. Melgarejo, J., Prats, D., Molina, A., Trapote, A., "A case study of urban wastewater reclamation in Spain: comparison of water quality produced by using alternative processes and related costs," *Water Reuse Desalin.*, vol. 6, no. 1, pp. 72–81, 2016.
97. Nader, M., Bastaki, A., "Performance of advanced methods for treatment of wastewater: UV/TiO2, RO and UF," *Chem. Eng. Process.*, vol. 43, no. 7, pp. 935–940, 2004.
98. Kitanoua, S., Hafidaa, A., Soukainaa, B., Mahi, M., Takya, M., and Elmidaoui, A., "Performance of an ultrafiltration membrane bioreactor (UF-MBR) in wastewater treatment," *Desalin. Water Treat.*, vol. 157, pp. 393–398, 2019.
99. Anantharaman, A., Chun, Y., Hua, T., J. Chew, and Wang, R., "Pre-deposited dynamic membrane filtration- A review," *Water Res.*, vol. 173, no. 115558, 2020.
100. Mutamim, N.S.A, Zainura, Z. N., Hassan, M.A., Olsson, G., "Application of membrane bioreactor technology in treating high strength industrial wastewater: a performance review," *Desalination*, vol. 305, pp. 1–11, 2012.
101. Yang, J., *Membrane Bioreactor for Wastewater Treatment*, 1st Editio. China: Bookboon, 2013.
102. Praneeth, K., Suresh, B.K., James, T., Sridhar, S., "Design of novel ultrafiltration systems based on robust polyphenyl sulfone hollow fiber membranes for treatment of contaminated surface water," . *Chem. Eng. J.*, vol. 248, pp. 297–306, 2014.
103. Shengji, X., Xing, L., Ji, Y., Bingzhi, D., and Juanjuan, Y., "Application of membrane techniques to produce drinking water in China," *Desalination*, 2008, https://doi.org/10.1016/j.desal.2007.01.142.
104. Benítez, F.J., Acero, J.L., Leal, A.I., González, M., "The use of ultrafiltration and nanofiltration membranes for the purification of cork processing wastewater," *J. Hazard. Mater.*, vol. 162, pp. 1438–1445, 2009.
105. Jack, N., "Ultrafiltration membranes offer alternative ways to comply with future discharge standards," *Water World*, 2006.
106. Shahidul, M.I., "'Research Towards Mitigating Clean Water Crisis ; Experiments with Separation technology," *Res. Bull. Fac. Eng. UNIMAS*, vol. 11, no. 4–11, 2018, [Online]. Available: www.feng.unimas.my.
107. Paulen, R., Fikar, M., "Optimal operation of batch membrane processes," *Cham, Switz. Springer*, p. 158, 2016.
108. Bernhard, S., Uwe, B. S., "S-Layer Ultrafiltration Membranes," vol. 11, no. 4, p. 275, 2021.
109. Huang, H., Schwab, K., Jacangelo, J., "Pretreatment for low pressure membranes in water treatment: A review," *Environ. Sci. Technol.*, vol. 43, no. 9, pp. 3011–3019, 2009.
110. Olsson, G., Nielsen, M., Yuan, Z., Lynggaard-Jensen, A., Steyer, J. P., "Instrumentation, control and automation in wastewater systems," *Instrumentation, Control Autom. wastewater Syst. IWA Publ.*, 2005.
111. Ganesh, R., Helia, S., Ryan, H., "Improving Membrane Treatment Energy Efficiency Through Monitoring the Removal of Colloidal Particle Foulants," 2021.
112. Chang, H., Li, T., Liu, B., Chen, C., He, Q., Crittenden,J.C., "Smart ultrafiltration membrane fouling control as desalination pretreatment of shale gas fracturing wastewater: The effects of backwash water," *Env. Int.*, vol. 130, no. 104869, 2019.
113. Nguyen, T.A., Yoshikawa, S., Ookawara, S., "Effect of operating conditions in membrane module performance," *J. Asean Eng.*, pp. 4–13, 2015.