Chapter 6

The Use and Potential of Membrane Technology for Wastewater Treatment in Post-COVID-19 Pandemic

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A. Introduction

The Coronavirus Disease 2019 (COVID-19) pandemic has posed severe threats to humans and the environment. The findings of severe acute respiratory syndrome coronavirus 2 (SARS-Cov-2) traces in wastewater and the practice of disinfecting outdoor spaces in several cities in the world including Indonesia, which can result in the entry of disinfectants and their byproducts into storm drainage systems and their subsequent discharge into rivers and coastal waters, raise the issue of environmental, ecological, and public health effects.

Paleologos et al. (2020) conducted a review of this case and reported that the presence of SARS-Cov-2 has been detected in untreated wastewater in several countries, such as in the Netherlands,

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Septiani, N. D., & Untari, D. W. (2022). The use and potential of membrane technology for wastewater treatment in post-COVID-19 pandemic. In R. Trialih, F. E. Wardiani, R. Anggriawan, C. D. Putra, & A. Said (Eds.), *Indonesia post-pandemic outlook: Environment and technology role for Indonesia development* (83–96). DOI: 10.55981/brin.538.c505
ISBN: 978-623-7425-85-4 E-ISBN: 978-623-7425-89-2

Australia, Greece, and the United States. SARS-Cov-2 macromolecules were found in the saliva, blood, and anal swabs of patients, raising the question of viral gastrointestinal infection and oral transmission routes for the virus. Van Doremalen et al. (2020) reported that SARS-Cov-2 may live from 4 until 72 hours on environmental surfaces, depending on the nature of the surface material. While a report from the US Centers for Disease Control and Prevention (CDC) suggested that the virus can survive up to 17 days in the environment (Moriarty, 2020).

Wastewater that is generated from handling SARS-Cov-2 contains a lot of bacteria, viruses, and disinfectants that contain chemical compounds and drugs that endanger public health. Waste from the medical laboratory needs to be handled more seriously because the chemicals used in the medical laboratory test process cannot be decomposed only by aeration or activated sludge. These materials contain heavy metals and infectious materials. Hence, it must be sterilized or normalized into non-hazardous waste. However, health facilities in hospitals and health centers usually use aerobic and anaerobic systems by using bacteria as a medium in decomposing pollutants for the wastewater. Thus, the increased use of disinfectants in this pandemic will disrupt the performance of wastewater treatment plants because many disinfectants could remove the bacteria in the system. For this reason, an effective solution is needed in the treatment of wastewater in the hospital and health facilities.

In order to minimize disease transmission from hospital wastewater that may have a high load of pathogens and drugs waste during a pandemic, Sozzi et al. (2015) suggested that these be first treated in-situ, before being discharged to the municipal sewerage network. Membrane technology is one of the solutions which are very effective in treating wastewater that contains disinfectants and biological waste (bacteria and viruses) so that it becomes non-hazardous waste.

B. Membrane

Membrane is a thin layer between two adjacent phases acting as a semipermeable (selective barrier) and regulating the exchange of substances between the two compartments. Membrane is widely used for medical treatment such as hemodialysis, water treatment plant (reverse osmosis), and wastewater treatment plant.

There is a classification of membranes based on the material source, cross-section structure, bulk structure, geometry, and separation regime. The classifications are as given:

1. Material source : organic or polymer, inorganic
2. Cross-section structure : symmetric, asymmetric
3. Bulk structure : integrally, composite
4. Geometry : flat sheet, tubular
5. Separation regime : porous, nonporous, ion exchange

Membrane material from organic or polymer is preferred to use over inorganic material. There are advantages of polymer material as membrane, such as many different types of polymeric material are commercially available, a large variety of different selective barriers, i.e., porous, nonporous, charged, and affinity can be prepared by versatile methods. Furthermore, the production of large membrane areas with consistent quality is possible on a technical scale at a reasonable cost based on reliable manufacturing processes, and various membrane shapes (flat sheet, hollow fiber, capillary shape, tubular, capsule) and formats including membrane modules with high packing density can be produced. A very well-defined regular pore structure is difficult to achieve, and the mechanical strength, the thermal stability, and the chemical resistance (e.g., at extreme pH values or in organic solvent) are rather low for many organic polymers.

There are examples of membranes from organic-or polymer-based on its materials. The classifications are as given:

- *Polysulfone* (PS) *and Polyethersulfone* (PES)

PS and PES membranes are widely used in microfiltration and ultrafiltration preparation, also for support in nanofiltration and reverse osmosis. The advantages of this material are, that it is stable in high temperatures, has wide pH tolerance (for pH 2–13), fairly good chlorine resistance, easy to fabricate membranes in a wide variety of configurations, and these materials have a flux or high permeability. Meanwhile, the disadvantages of these materials are, that it has a low-pressure limit which is typically 100 psig or 7 atm with flat sheet membrane and 25 psig or 1.7 atm with hollow fibers, these materials are also hydrophobic.

- *Cellulose acetate* (CA)

Cellulose acetate is prepared from cellulose by acetylation, i.e., reaction with acetic anhydride, acetic acid, and sulfuric acid. The advantages of this material are, it is hydrophilic, relatively easy to manufacture, the raw material is a renewable resource, and it can be prepared into a membrane with a pore size range that varies from microfiltration to reverse osmosis. The disadvantages of this material are, it has a fairly narrow temperature and pH range (3–7), poor resistance to chlorine, and it is highly biodegradable which can make the membrane not last longer to be used.

- *Polyamide* (PA)

Polyamide is characterized by having an amide bond in structure (-CONH-). Polyamide can be divided into three groups, i.e., aliphatic polyamide, semi-aromatic polyamides, and aromatic polyamides. The advantages of this material are, it has a wider pH and temperature rather than CA material, and it is also hydrophilic. The disadvantage is this material has poor resistance to chlorine.

C. Membrane Processes

As one of the most recent advances, membrane technology has developed as an effective technique for treating various types of wastewater streams. Impurities are reduced to the required level by using this method. A membrane process is good because it does not use much energy, can be used for a long time, and is easily scaled up. It could be organic or inorganic, depending on the material in the process. There are five membrane processes based on the pore size. The classifications are as given:

1. *Microfiltration* (MF)

Microfiltration is a pressure-driven process where separated compounds are in nanoparticles with a diameter of 0.1–0.2 μm. It is used as the first pre-treatment in NF and RO membrane processes. MF does not remove organic matter. However, when pre-treatment is applied, the increased removal of organic material can occur. MF can be used as a pre-treatment to RO or NF to reduce fouling potential. The main disadvantages of MF are that it cannot eliminate contaminants that are < 1 mm in size. In addition, MF is not an absolute barrier to viruses. However, when used in combination with disinfection, MF appears to control these microorganisms in water.

2. *Ultrafiltration* (UF)

Ultrafiltration membrane process can separate compounds in which the particle size is between 0.005 and 10 μm, which is between MF and RO. UF membranes are highly prominent water filters with low energy consumption in the removal of pathogenic microorganisms, macromolecules, and suspended matter among others. However, UF has some limitations including its inability to remove any dissolved inorganic substances from water and regular cleaning to maintain high-pressure water flow.

3. *Nanofiltration* (NF)

Nanofiltration is capable of removing ions that contribute significantly to the osmotic pressure hence allowing operation pressures that are lower than those RO. For heavily polluted water, NF needed a pre-treatment process to be effective.

4. *Forward Osmosis* (FO)

Forward osmosis is a natural occurrence where the solvent moves from a region of lower concentration to the higher concentration region across a permeable membrane. This process is found to be highly efficient with low-rate production of brine and is well studied as it promises to solve water problems. However, regeneration of the draw solution is highly expensive for the desalination process, hence the use of NF or RO for regeneration of the draw solution.

5. *Reverse Osmosis* (RO)

Reverse osmosis is a pressure-driven technique used to remove dissolved solids and smaller particles. RO is only permeable to water molecules. The applied pressure on the RO should be enough hence water can be able to overcome osmotic pressure. The pore structure of RO membrane is tighter than UF, they convert hard water to soft water, and they are practically capable of removing all particles, bacteria and organics, and it also requires less maintenance. Some disadvantages of RO are it includes the use of high pressure which is expensive compared to other membrane processes and are also prone to fouling. RO has very small pores and is able to separate particles smaller than 0.1 nm.

Membrane Module and Selection (Ezugbe & Rathilal, 2020)

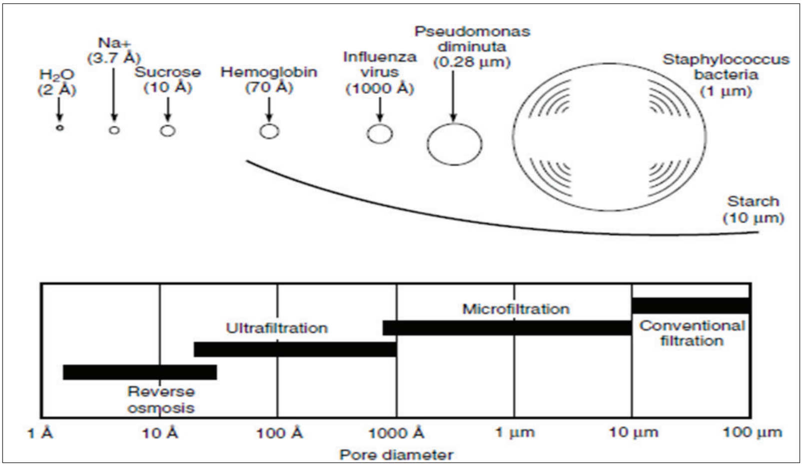
There are four selections of membrane based on the membrane module. The classifications are as given:

1. Plate-and-Frame Module. It is the oldest developed modular, used for high suspended particles wastewater treatment.
2. Tubular Module. It is an exterior casing (shell). Tubes are inserted into which the fluid to be processed is pumped under pressure. To treat feed having high solid contents, the water permeate out from the membrane goes via the tubing into the housing.
3. Spiral Wound Modular. This module is most often used in RO and NF procedures. The treated water fills the spiral wound module perpendicular to the membrane.
4. Hollow Fiber Module. In a pressure vessel, closed or open end. Depending on its intended usage, it might be shell-side (outside) or bore-side (inside).

D. Membrane Technology for Virus Removal in Wastewater

The use of membrane technology for wastewater treatment especially in the post-pandemic of SARS-Cov-2 ought to consider the size of virus particles. Varga Z et al. (2020) stated that SARS-Cov-2 size ranges from 60 to 140 nm in diameter. In another recent research, virus-like particles in infected SARS-Cov-2 patients were 70–110 nm in diameter. This state is similar to another study, where Bar-On et al. (2020) found that SARS-Cov-2 is an enveloped virus with a diameter of 100 nm. In recent years, virus reduction has become a priority in treating virus-contaminated wastewater/drinking water. According to (Chen et al., 2021), there are a lot of countries and institutions that research how to remove viruses from water, but they are mainly in the United States, France, Canada, the Netherlands, China, Spain, Japan, South Korea, etc.

Based on the size of virus particles, we can decide which membrane is used. In the case of SARS-Cov-2, the membrane process that

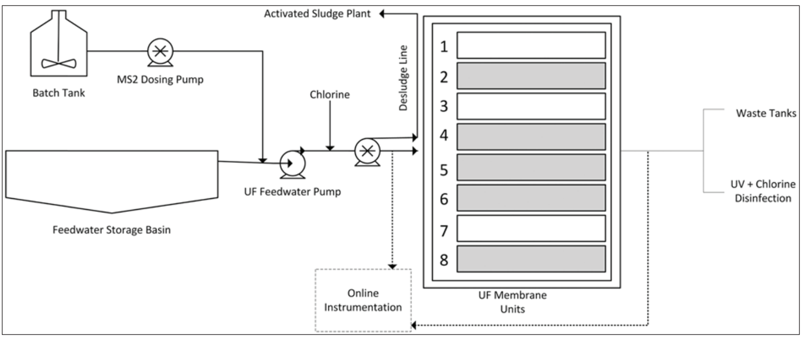


Source: Reeve (2016)

Figure 6.1 Particles Size and Membrane Filtration Range can be used is UF or RO. With the advantages and disadvantages of both processes, we can determine which process is more effective in installation, maintenance, and the ability to filter the virus and other wastewater pollution.

Reeve P. et al. (2016) stated that UF membrane technology is mostly used widely in wastewater treatment recycling schemes as a physical barrier to eliminate human pathogens including bacteria, protozoa, and viruses. But in Australia, where they experiment with the membrane, treatment implementation for UF requires validation to demonstrate that the process can provide the effectiveness of pathogenic microorganisms. Furthermore, Reeve P. et al (2016) designed a schematic of the UF membrane to demonstrate that the membrane can work effectively for viruses.

In the graph above, a batch tank with MS2 dosing is a highly concentrated stock culture that was selected as the virus surrogate. In this case, the wastewater that was contaminated with the virus. The feed water is used to minimize the suspension of suspended solids, filled and isolated to allow the chlorine or disinfectant to decay from the chlorinated secondary effluent process. Online instrumentation is used to monitor the feed and quality parameters of filtrate water



Source: Reeve (2016)

Figure 6.2 Schematic of the UF Membrane Testing Configuration which are pH, temperature, free and total chlorine, conductivity, and turbidity. The key to this online instrumentation for UF performance are trans-membrane pressure, resistance, and flow rate.

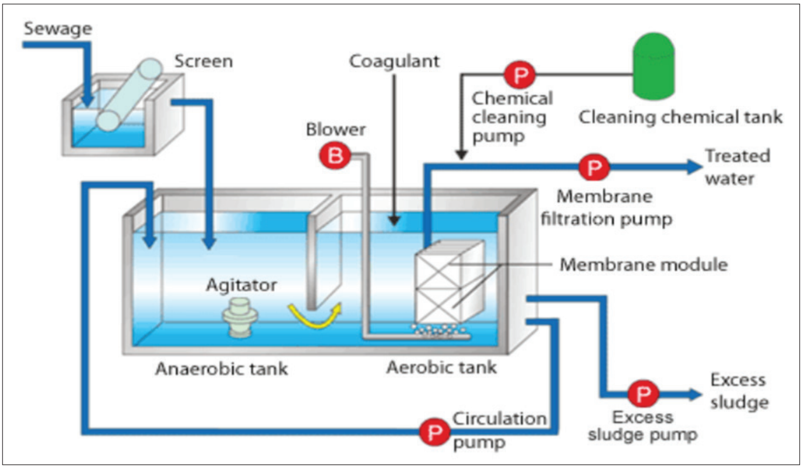
Categories and Elimination of Viruses in Water Treatment

Viruses are non-cellular, 10–100 nm-sized particles that contain nucleic acids (DNA and RNA). Live in the host for life and are infective, making them difficult to remove. UV disinfection is ineffective against Adenovirus, which has double-stranded DNA and is often found in WWTPs (Hata et al., 2013). Also, enteroviruses, rotaviruses, hepatitis A viruses, and noroviruses may live for months in natural water (Brooks et al., 2020). Most viruses in WWTP influent were negatively charged since the isoelectric point (IEP) is lower than the influent pH. There are two types of viruses: those living outside of host cells, cohabitating with microbes, and living within host cells. As a rule, viruses are smaller than the pores of MF membranes but more significant than those of NF and RO membranes. MF removes viruses by a factor of 0.3–2.2 (Chen et al., 2021). The surface of the vast majority of viruses is mostly made of proteins that give them their unique properties. Techniques including filtration, flocculation, coagulation, sedimentation, and disinfection help decrease viruses in wastewater and provide virologically safe recycled water. In requirement to formulate effective wastewater reclamation systems, users need to know how well each wastewater treatment unit removes viruses on average, and this is called a "viral LR credit". (Teunis et al., 2009)

It has been advocated by current standards (Amarasiri et al., 2017) regarding wastewater reclamation operations that the numerous systems in which successive wastewater treatment procedures are established in order to ensure that a total virus removal efficiency assessed by virological risk assessment surpasses the predetermined performance goal, should be used to limit viral infection risks for any kind of reclaimed wastewater use. Various academic difficulties need to be addressed further, such as 1) how to consider left-censored datasets in the computation of virus removal efficiency and 2) what indicators and procedures are acceptable for verifying virus removal/ disinfection effectiveness in daily wastewater reclamation systems.

E. Membrane Bioreactor (MBR)

In some studies, researchers started to combine membranes with reactors that consist of aerobic or anaerobic bacteria to recycle the wastewater from hospitals or health facilities. This combination is called a membrane bioreactor (MBR). The process of membrane bioreactor is first introduced in the late 1960s after the commercialized ultrafiltration and microfiltration is improved. The new development of the membrane bioreactor was started in 1989 by Yamamoto and colleagues with the idea to sink the membrane inside the bioreactor. The main process inside the membrane bioreactor is a combination process of a membrane in a bioreactor to filter biomass (Hernaningsih, 2014).



Source: Wardhani (2015)

Figure 6.3 MBR System for Wastewater

In the last five decades, strengthened by the rapid improvement in engineering and materials science, the use of membrane technology in water treatment has become increasingly popular with one example being the MBR. Membrane bioreactor has two forms, which are aerobic membrane bioreactor (AeMBR) and anaerobic membrane bioreactor (AnMBR). (Zhu Y, 2021)

There are many types of membrane bioreactor systems. It is developed for two processes, suspended growth and attached growth. The most general type that is mostly used in submerged membrane bioreactor (SMBR) and external membrane bioreactor (EMBR). Submerged MBR is the type that is mostly used, where the membrane module is installed inside the reactor-activated sludge, which can be seen in Figure 6.3.

Removal efficacy of the MBR is mostly based on the following four processes (Chen et al., 2021):

1. Viruses are attracted to sludge particles through adsorption. Virus aggregates may bind to sludge particles that contain numerous bacteria and organic substances bigger than membrane pore size, reducing virus passage probability.
2. Interception of membrane
3. The cake and gel layers adsorb to the membrane surface. A virus's behavior in an aqueous medium is determined by viral protein (including hydrophobic and charged areas) and not by the membrane modules of MBRs with varying pore sizes. These membrane modules exhibit no evident change in the retention with the same virus water quality factors, including pH and temperature.
4. In MBRs, adsorption and aggregation processes via biofilm and cake layer rather than size exclusion are employed to remove viruses (typically from 0.1 to 0.4 μm).

Permeate is pumped out of the membrane module and suspended solids are retained by the membrane and removed back into the tank. Sludge formation occurs in the reactor. Submerged MBR is very popular because it does not need large land space, the energy need is low, and also has good filterability. However, submerged MBR requires larger and better membrane for filterable wastewater, which backwash cleaning is more often and lower membrane usage than external MBR. Submerged MBR has operating conditions according to Table 6.1.

Table 6.1 Operating Condition of Submerged MBR

Parameter	Value
Instant flux (L/m^2h)	25–35
Long term flux (L/m^2h)	15–30
Trans-membrane pressure (kPa)	20
Biomass concentration (gMLSS/L)	5–25
Sludge age (day)	> 20
Sludge production (kgSS/kgCOD)	< 0.25
Detention time (hour)	1–9
Food to microorganisms ratio	< 0.2
Volumetric load (m^3/day)	0–20
Air flow rate (Nm^3/hour per module)	8–12
Operational temperature (^oC)	10–35
Operational pH	7–7.5
Backwash frequency (minute)	5–16
Backwash time (second)	15–30
Energy consumption for filtration (%)	0.2–0.4
Energy consumption for aeration (%)	80–90
Energy consumption for permeate pump (%)	10–20

Source: Wardhani (2015)

The use of membrane bioreactor not only to manage wastewater pollution but also can be used as wastewater reclamation to produce drinking water. However, more parameters analysis should be done to release the wastewater filtrate as clean water that is safe for drinking water.

F. Conclusion

In this chapter, the membrane technology and processes are explained, including types and selection of membranes. Types of membrane that can be used in this case are ultrafiltration (UF) or reverse osmosis (RO), based on the size of membrane pore and virus particles. Several aspects which should be consider of choosing these types of membranes are the availability of the membrane, effectiveness of the process, maintenance and also the cost estimation. In this chapter, also explained about membrane bioreactor that can also treat wastewater, which is a combination of aerobic and anaerobic tank with membrane filtration inside the tank. Using membrane technology can give benefits for wastewater treatment than common WWTPs process.

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