

CHAPTER V

MEMBRANE WATER TREATMENT TECHNOLOGY

5.1 Introduction

This chapter reported on the research findings for the second objective and research question. The research question for this chapter is what is membrane water treatment technology? The discussion is about membrane water treatment based on its characteristics, material, function, type, etc.

5.1 Membrane Technology

Membrane technologies have been used in many areas, not only for water treatment but also for energy sustainability. It is also used in the context of the water industry to improve the quality of water for use, reuse or discharge to the environment. So, it plays a significant role and is already applied in scale-industry industries (Le and Nunes, 2016), especially in producing water treatment to remove all undesired components. When we push something, the driving force will be used through the material, like a membrane. This membrane plays an importance role in this action. This role of the membrane is stated in al-Quran as follows:

﴿وَهُوَ الَّذِي مَرَجَ الْبَحْرَيْنِ هَذَا عَذْبٌ فُرَاتٌ وَهَذَا مِلْحٌ أُجَاجٌ وَجَعَلَ بَيْنَهُمَا بَرْزَخًا وَحِجْرًا مَحْجُورًا﴾

Which means, “And it is He who has released [simultaneously] the two seas, one fresh and sweet and one salty and bitter, and He placed between them a barrier and prohibiting partition”.

(Al-Quran. Al-Furqan 25:53)

Membrane technology has played an essential role in developing more efficient and selective production to reduce raw materials, energy and water consumption and minimise wastewater and solid waste. Hence, membrane processes have been introduced in industrial operations to treat the water and recycle process water (Bernardes et al., 2014). The membrane is a porous thin layered material that allows water molecules to pass through it but simultaneously restricts the passage of bacteria, viruses, salts and metals. Membranes use either pressure-driven forces or electrical technologies. Pressure-driven membrane technology is a perfect method for water purification to any desired quality (Kumar et al., 2014).

Membrane separation processes are advanced methods for the treatment of water and wastewater. Membranes separate substances depending on pore and molecule size. It is a reliable and automated process for wastewater treatment (Gehrke et al., 2015). The challenge of membrane technology is the inherent trade-off between membrane selectivity and permeability. This technique requires high-energy consumption due to the pressure-driven process. Fouling of membranes makes the process very complex and reduces the lifetime of membranes and membrane modules (Qu et al., 2013). The performance of the membrane system depends on the type of membrane material. Functional nanomaterial

inclusion into membranes is advantageous in improving membrane permeability, fouling resistance, and mechanical and thermal stability.

Thus, a membrane can be described as a thin layer capable of separating materials as a function of their physical and chemical properties when a driving force is applied across the membranes. The membrane process employs several types, including MicroFiltration (MF), NanoFiltration (NF), UltraFiltration (UF) and Reverse Osmosis (RO) (Pellegrin et al., 2011). Hence, this membrane functions to separate and filter the harmful and unnecessary substances from water to come up with fresh water to be consumed by humans safely and accepted from a scientific perspective. Membrane processes can substitute single purification processes in traditional water treatment or combine to make an integrated membrane process (D. Zioui et al., 2015).

5.2 Membrane Fabrication Techniques

The membrane fabrication technique forms membranes in different arrangements to meet industrial and domestic demands. Many casting techniques have been implemented to obtain different types of membranes like flat-sheet membranes (casting), hollow fibre membranes (spinning) and composite membranes (dip-coating) (Ladewig & Al-Shaeli, 2017).

5.2.1 Flat Sheet Membrane

A flat sheet membrane is a simple method to prepare membranes for research purposes. This type of preparation is straightforward and very effective for characterising on a laboratory scale. A dead-end cell station is used for measuring the water flux of

membranes. This flat sheet membrane is cast mainly by hand or semi-automatically using a glass plate and not on a non-woven polyester (Ladewig & Al-Shaeli, 2017).

5.2.2 Hollow Fibre Membrane

Hollow fibre membranes are more applicable for industrial applications due to their effectiveness and are cheaper than flat sheet membranes. This membrane type has a higher surface or volume ratio, leading to more excellent pressure resistance than flat sheet membranes. Next, hollow fibre membranes have minimum dead space so that they can be physically cleaned by frequent backwash and have a more extended life membrane. It is also designed with specific dimensions to minimise membrane fouling (Ladewig & Al-Shaeli, 2017). Hence, the suitable fabrication membrane needs to be applied to the suitable water treatment used to enhance the membrane process's effectiveness.

5.3 Types of Membranes

The water treatment process employs several types of membranes, including MicroFiltration (MF), NanoFiltration (NF), UltraFiltration (UF) and Reverse Osmosis (RO) membranes. MF membranes have the largest pore size and typically reject large particles and various microorganisms. At the same time, UF membranes have smaller pores than MF membranes. Therefore, in addition to large particles and microorganisms, they can reject bacteria and soluble macromolecules such as proteins. RO membranes are effectively non-porous (Sagle & Freeman, 2004).

Therefore, most particles can be eliminated, excluding many low molar mass species such as salt ions, organics, etc. NF membranes are new and are also called “loose”

RO membranes. They are porous membranes, but the holes are on the order of ten angstroms or smaller; therefore, their performance is comparable to that of RO and UF membranes. Ultrafiltration can separate and concentrate macromolecules by using membranes with micropores of 1–100 nm. MF and UF technologies are typically used to treat water with high turbidity (Sagle & Freeman, 2004).

The membrane technology has played an essential role in developing more efficient and selective manufacturing with lower raw material, energy, and water consumption and reducing wastewater and solid waste. Membrane processes have been implemented in industrial settings to treat water, recycle process water, and potentially reuse and recover by-products. Different membrane separation processes treat water, sewer and industrial wastewater. (Sagle & Freeman, 2004).

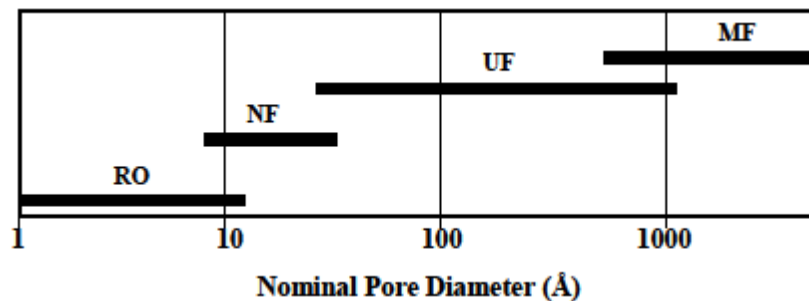
Pressure-driven membranes, MF, UF, NF, and RO, are the membrane processes used in water and wastewater treatment with a differential pressure applied across a membrane in pressure-driven membrane separation processes. The membrane functions as a semi-permeable barrier and may have different selectivity for different compounds (Sagle & Freeman, 2004).

Microfiltration is typically used to remove suspended solids or bacteria by using membranes with pore diameters ranging between 0.1 and 10 μ m and also the transport mechanism is stereochemical exclusion, where the molecules with a radius greater ensure the removal of viruses and bacteria from drinking water or as a pre-treatment in reverse osmosis systems. Reverse osmosis separates salts and small organic molecules from liquid streams using membranes with dense active layers, where the preferred transport mechanisms are often attributed to the solution. Due to the high density of the active layer,

operating pressures have to be much higher than microfiltration and ultrafiltration (Sagle & Freeman, 2004).

Next, the nanofiltration process is an intermediate separation process between reverse osmosis and ultrafiltration which is commonly used in separating organic solutes with a low molecular weight range of 200–1000 Da in the partial demineralization (essentially polyvalent salts) of liquid streams. The transport mechanisms that operate in these types of membranes are diffusion (as in reverse osmosis) and molecular exclusion (as in ultrafiltration), and the electrostatic interactions are also detected, which lead to the selective removal of polyvalent ions (Sagle & Freeman, 2004).

Membrane technology continues to advance with proven success in water treatment. However, some major problems still need attention: membrane fouling and membrane chemical stability. Reduced fouling would make membranes even more cost-effective by extending their operational lifetime and lowering their energy. Work in this area has focused on surface modification of membranes and increasing the pre-treatment of the feed water before it reaches the membranes (Sagle & Freeman, 2004).



Source: Sagle & Freeman (2004)

Figure 5.1: Range of Nominal Membrane Pore Sizes

The types of membranes and their pore sizes can be simplified as follows:

Table 5.1: Types of Membranes and the Pore Sizes

Membrane Filtration	Separation Specification	Applications/ Removal
Microfiltration (MF)	>100,000 Daltons 10 - 0.1 μ m	bacteria, viruses, suspended solids etc
Ultrafiltration (UF)	10,000 to 100,000 Daltons 0.05 - 5 e-3 μ m proteins,	proteins, starch, viruses, colloid silica, organics, dyes, fats, paint solids etc
Nanofiltration (NF)	1,000 to 100,000 Daltons 5 e-3 - 5 e-4 μ m starch,	starch, sugar, pesticides, herbicides, divalent ions, organics, BOD, COD, detergents etc
Reverse Osmosis (RO)	salts and lower MWCO 1 e-4 - 1 e-5 μ m	metal ions, acids, sugars, aqueous salts, dyes, natural resins, monovalent salts, BOD, COD, ions etc

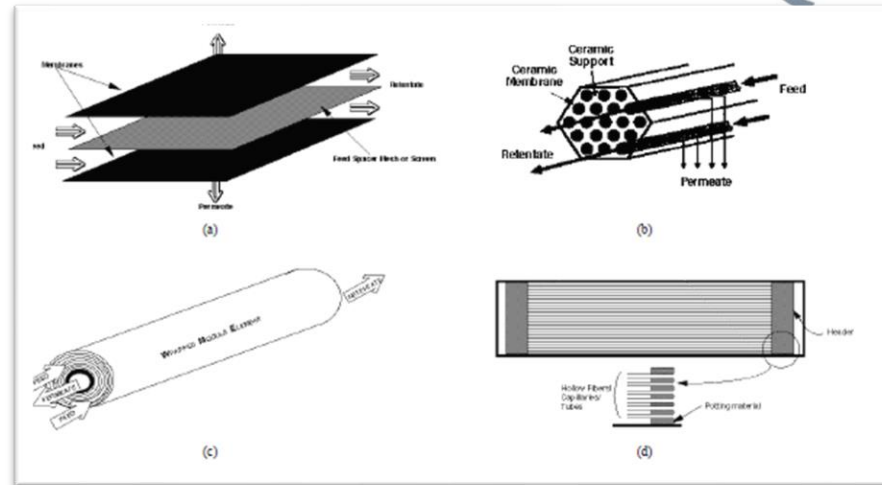
Source: Modified from Vincentus (nd)

5.4 Membrane Characteristics

Membranes are made up for their unique purpose of filtering water; one of the membrane's uniqueness is its porousness. According to Ingo Pinnau (2008), a microfiltration membrane allows water, monovalent ions, multivalent ions and viruses but rejects bacteria and suspended solids. The types of membranes give different functions and abilities for filtration. The ultrafiltration membrane allows water, monovalent ions and multivalent ions but rejects viruses, bacteria and suspended solids. At the same time, the nanofiltration membrane allows water and monovalent ions but rejects multivalent ions, viruses, bacteria and suspended solids. Then, the reverse osmosis membrane allows water only and rejects monovalent ions but rejects multivalent ions, viruses, bacteria and suspended solids.

5.5 Membrane Modules

Membrane technology works in two types of filtrations, which are cross-flow filtration and dead-end filtration (Vincentus, nd)

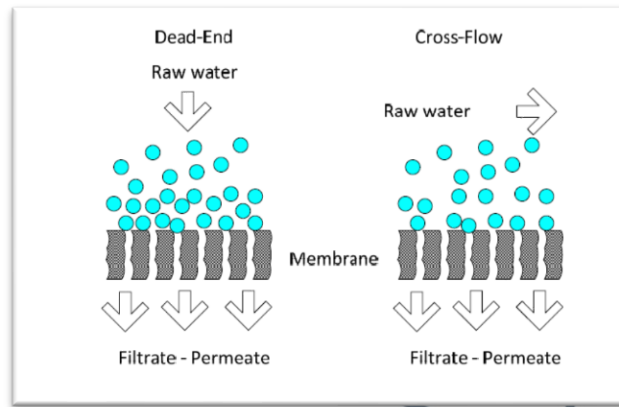


Source: (Wolfgang Gunhert et al, 2013)

Figure 5.2: Membrane Technology Application

Sagle & Freeman (2004) stated that there are four modules: plate-and-frame, tubular, spiral wound and hollow fibre. Baker (2004) said that the plate-and-frame module is the most straightforward configuration and consists of two end plates: the flat sheet membrane and spacers. In tubular modules, the membrane is often on the inside of a tube, and the feed solution is pumped through the tube. The spiral wound module is the most popular module in the industry for nanofiltration or reverse osmosis membranes. This module has a flat sheet membrane wrapped around a perforated permeate collection tube. The feed flows on one side of the membrane and the permeate is collected on the other side of the membrane and spirals in towards the centre collection tube. Hollow fibre modules used for seawater desalination consist of bundles of hollow fibres in a pressure vessel. It can have a shell-

side feed configuration where the feed passes outside the fibres and exits the fibre ends. Hollow fibre modules can also be used in a bore-side feed configuration where the feed is circulated through the fibres. It can be simplified as follows figure:



Source: Sagle & Freeman (2004)

Figure 5.3: Membranes Modules

The figure shows a schematic of (a) plate and frame, (b) tubular, (c) spiral wound and (d) hollow fibre modules.

5.6 Membrane Operation

The operation of the membrane varies between the products and types of membranes. No electricity is required if the process is manual by pumping or gravity used to force the water through the membrane. The driving force is required to enhance the membrane's operation in this process. This may be gravity used for microfiltration and ultrafiltration membrane processes and pressure or vacuum for nanofiltration and reverse osmosis processes (Baker, 2004).

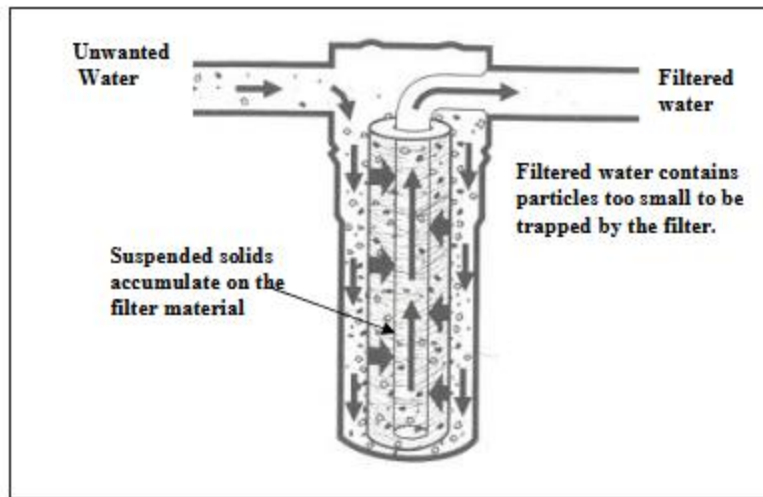


Figure 5.4: Operation of Membrane Water Treatment

Figure 5.4 shows the operation of membrane water treatment by flowing the unwanted water of sewage water into the filter. Then the suspended solids from the sewage water are accumulated on the filter material. Next, filtered water that contains tiny particles trapped by the filter then filtered water flows out to be consumed by humans.

5.7 Membrane Materials

Membranes for water filters are divided into two types; organic materials and inorganic materials (Sagle & Freeman, 2004). In contrast, Ladewig and Al-Shaeli (2017) stated that there are three fundamental categories of membrane materials: organic materials, inorganics materials and biological materials.

Organic materials are polymeric, either cellulose-based or composed of modified organic polymers. Inorganic materials are ceramics materials and metals. In contrast, a biological membrane or biomembrane is a selective barrier around or within a cell in a living organism. However, this biological membrane is unsuitable and cannot meet the

industrial requirement because of the thermomechanical stability and productivity. Hence, organic materials (polymeric-based) membranes are primarily used in research and commercial because of their various polymers. But now, composite and inorganic membrane materials have gained attention for their potentially high performance, long lifetime and availability from using polymeric membranes (Ladewig & Al-Shaeli, 2017).

5.7.1 Organic Membrane Materials

Organic or polymeric membranes are the most widely used materials in wastewater treatment applications. These materials are accessible to prepare, have reasonable cost, have high efficiency for removing dispersed oil, particles and are emulsified, are small and have lower energy requirements (Ladewig & Al-Shaeli, 2017). But, the main limitation of these polymeric materials is their relatively high hydrophobic property which can lead to severe membrane fouling. Then, it needs frequent membrane cleaning and influencing the shelf life of the membrane and its applications. The polymer materials that are usually used for water treatment applications are as follows:

Table 5.2: Polymeric Materials Used for Membrane and The Membrane Processes

No.	Polymer	Membrane Processes
1.	Cellulose acetates	Reverse Osmosis Ultrafiltration Microfiltration
2.	Cellulose Nitrites	Microfiltration
3.	Cellulose regenerated	Ultrafiltration
4.	Polyacrylonitrile	Ultrafiltration
5.	Polyetherimides	Ultrafiltration
6.	Polyethersulfone	Ultrafiltration Microfiltration
7.	Polyethylene terephthalate	Microfiltration
8.	Polytetrafluoroethylene	Microfiltration
9.	Polyamide, aliphatic	Microfiltration
10.	Polyamide, aromatic	Microfiltration

11.	Polyamide, aromatic. In situ synthesised	Reverse Osmosis Nanofiltration
12.	Polycarbonates, aromatic	Nanofiltration Microfiltration Reverse Osmosis
13.	Polyether, aliphatic crosslinked, In situ synthesised	Reverse Osmosis Nanofiltration
14.	Polyimides	Nanofiltration
15.	Polypropylene	Microfiltration
16.	Polysiloxanes	Nanofiltration
17.	Polysulfone	Ultrafiltration
18.	Polyvinylidene flouride	Ultrafiltration Microfiltration

Source: Adapted from Ladewig and Al-Shaeli (2017)

5.7.2 Inorganic Membrane Materials

Membranes also can be produced from inorganic materials such as ceramics or metals (Baker, 2004). Inorganic membrane materials are generally categorised into four groups: glass membrane, ceramic membrane, metallic membrane and carbon membrane. The latest one is zeolitic membranes. The metallic membrane is obtained from the sintering of metal powders like stainless steel, molybdenum, or tungsten.

Ceramic membranes are crucial as they have a higher chemical, thermal and mechanical stability than organic membranes. Ceramic membranes are prepared by the combination of metals like aluminium, titanium, silicon or zirconium, zinc, tin, and iron with non-metal in the form of oxide, nitride or carbide to form a variety of inorganic nanoparticles such as carbon nanotubes, alumina or aluminium oxide, titanium oxide, zirconium dioxide or zirconia. Zinc oxide, silver, tin oxide. Sintering or sol-gel techniques are usually used to prepare ceramic membranes.

According to Siti Khadijah (2015), ceramic materials can be categorised into two types which are high-cost ceramic materials (aluminium oxide, titanium oxide, zirconium dioxide) and low-cost ceramic materials (powder-like clay, dolomite, apatite, fly ash,

natural raw clay and kaolin (China clay). Kaolin is the cheapest membrane raw material, and it is easily purchased in Malaysia (Siti Khadijah, 2015). While glass membranes can be regarded as ceramic membranes. Glass membranes such as silica are generally prepared by leaching technique.

Carbon membranes, called Carbon Molecular Sieve membrane (CMS), are porous solid membranes containing constricted holes responsible for approaching the molecular dimension of diffusing gas molecules. So, different sizes of molecules can be efficiently separated through molecular sieving. This carbon material can be prepared by pyrolysis of thermosetting polymers like poly acrylonitrile, cellulose triacetate, phenol formaldehyde and poly (furfural) alcohol. The recent one is zeolitic membranes that have very narrow pore sizes and can be used in gas separation, pervaporation and separation of ions from an aqueous solution of reverse osmosis (Ladewig & Al-Shaeli, 2017).

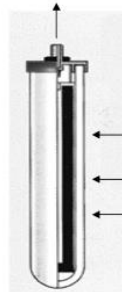


Figure 5.5: The Ceramic Membrane Filter

Next, the inorganic membrane materials advantages and disadvantages are as follows:

Table 5.3: Advantages and Disadvantages of Inorganic Membranes Compared to Polymeric Membranes

No.	Advantages	Disadvantages
1.	Long-term stability at high temperatures	High capital cost
2.	Resistance to a harsh environment like chemical degradation, pH and so on	Embrittlement phenomenon
3.	Easy cleanability after fouling	The low permeability of the high hydrogen selective (dense) membrane at low membranes
4.	Inertness to microbiological degradation	The difficulty of achieving high selectivity in large-scale microporous membranes
5.	Resistance to high-pressure drops	Low membrane surface per model volume

Source:(Gallucci et al., 2011)

It has excellent thermal and chemical stability compared to polymeric membranes (organic materials) and has antifouling properties due to the hydrophilic nature of organic material. But, there are some limitations to using inorganic materials. Thus, according to Sagle and Freeman (2004), most microfiltration, ultrafiltration, nanofiltration, and reverse osmosis membranes are synthetic organic polymers. Microfiltration and ultrafiltration membranes are often made from the same materials, but both are prepared under different membrane formation conditions for different pore size production Pinnau and Freeman (2000). According to Baker (2004), microfiltration and ultrafiltration membranes usually are made up of polymers, including poly (vinylidene fluoride), polysulfone, poly (acrylonitrile) and poly (acrylonitrile)-poly (vinyl chloride) copolymers. Poly (ether sulfone) is also commonly used for ultrafiltration membranes.

Microfiltration membranes include cellulose acetate-cellulose nitrate blends, nylons, and poly (tetrafluoroethylene). In comparison, reverse osmosis membranes are made up of either cellulose acetate or polysulfone coated with aromatic polyamides.

Nanofiltration membranes are made from cellulose acetate blends or polyamide composites like the reverse osmosis membranes or could be modified forms of ultrafiltration membranes such as sulfonated polysulfone (Nunes & Peinemann, 2001). Thus, the summary of the materials used for each type of membrane can be simplified as follows:

Table 5.4: Summarization of Membrane Types with Suitable Material Used

Membrane Process/ Types	Materials
Microfiltration	Ceramic Polymeric
Ultrafiltration	Polymeric
Nanofiltration	Polymeric
Reverse Osmosis	Polymeric

Source: Nunes & Peinemann (2001)

5.8 Membrane Water Treatment for Domestic Purposes

Wastewater produced by daily activities such as washing dishes, showering, laundry, and toilet sewage contributes to municipal wastewater or sewage that needs to be treated. This municipal wastewater contains biodegradable compounds and limited chemicals rather than industrial sewage, which can be treated using activated sludge systems (Le & Nunes, 2016). This activated sludge system contains a membrane bioreactor (MBR) which integrates either microfiltration or ultrafiltration membrane into conventional activated sludge (CAS) reactor to separate the sludge and enable to remove of a high amount of Biochemical Oxygen Demand (BOD), Total Organic Compound (TOC) and eliminate Total Suspended Solid (TSS). Many countries have applied membrane technology to treat domestic and municipal water, such as Singapore (2006), Japan, the USA, Netherlands, France, Korea, Germany and the United Kingdom (2011) (Le & Nunes, 2016).

The Nano Membrane Toilet (NMT) was developed by Cranfield University, UK, in 2011. The waterless, hygienic toilet is designed to turn human waste into pathogen-free water and encapsulate briquettes for irrigation and fertilizer using membrane technology (Parker, 2014). Singapore has also used membrane technology to operate sewage in tropical environments using a membrane bioreactor system since 2006 (Tao et al., 2008). Thus, it is proven that this membrane technology can give a solution for environmental conservation for saving water use.

5.9 Conclusion

Thus, the membrane field has applied and advanced immensely. This technology is economical, environmentally friendly, versatile and easy to use. Thus, membranes are a leading choice for water purification applications and should continue for many years.