REVIEW ON THE FACTORS AFFECTING ULTRAFILTRATION HOLLOW FIBER MEMBRANE OPERATIONAL PERFORMANCE IN WATER TREATMENT

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ABSTRACT. Ultrafiltration has been applied in the water treatment system since the last twenty years. Among the membrane modules available, compact and self-supporting hollow fiber membrane has been widely used as ultrafiltration membrane configuration. In this paper, the factors that have influence on ultrafiltration hollow fiber membrane are reviewed. The highlight is on the operational performance of the membrane. The factors are primarily membrane material, backwashing and pre-treatment, as well as transmembrane pressure (TMP) and permeate flux. These factors are important as points of reference when evaluating the operational performance of the ultrafiltration hollow fiber membrane. Thus, enable appropriate and better judgement in selecting water treatment system.

Keywords- Water treatment, membrane processes, Ultrafiltration (UF), Hollow fiber membrane

INTRODUCTION

In membrane processes, the success of any separation system involving membrane depends on the quality and suitability of the membrane incorporated in the system. Conventionally, water has been treated primarily using physical-chemical treatment such as sand filtration, disinfection i.e. chlorination and coagulation-flocculation via sedimentation process. Not only these conventional methods required large area of operations that would require high operational cost, but may also be incapable to treat several persistence pollutants (Kuch and Ballschmiter, 2001, Bolong et al, 2009a).

Membrane processes are becoming more popular in water treatment because the processes can disinfect water without chemical additions and avoid the formation of toxic disinfection by-products (Rana et al., 2005). Not only that, membrane technology has received more interest in recent years due to stringent standard for water supply and effluent discharge. With its advantages such as small operation area, high filtration efficiency as well as direct operational handling, membrane emerged as a favourable filter media for water treatment system. However, the limitation such as membrane...
fouling and operational life would be other factors to be considered. Further explanations of the
disadvantages were also discussed in the latter section of this paper.

The main configurations of polymeric membranes can be grouped as flat, spiral wound, tubular and
hollow fiber. Hollow fiber membrane configuration has the advantage of compact design with very
high membrane surface areas (Baker, 2004). Furthermore, hollow fiber configuration in water
treatment and reuse is favourable due to its large membrane area per unit volume of membrane
module. Hence, resulting in higher productivity, mechanically self-support which can be backwash for
liquid separation to provide good flexibility as well as easy handling during module fabrication and in
the operation (Chung et al., 2001). Many studies investigate on how to improve the filtration
behaviour of hollow fiber membranes to optimize its filtration performance. From many studies
conducted, it was found that the general filtration behaviour of hollow fiber membranes is
characterized by treatment operational such as time-dependent non-uniform distribution of
transmembrane pressure, flux, and filtration resistance along the fiber due to lumen-side pressure drop
induced by permeate flow (Chang et al., 2008). In choosing the right configuration for a water
treatment system, the module may be tested and evaluated first. For example, Groendijk and de Vries
(2009) tested three types of membrane configurations by evaluating the fouling behaviour of each
membrane before selecting the suitable membrane for their water treatment system.

It is understood that the membrane configuration would be the main important factors in most of these
work. However membrane performance in a complete water treatment system is also affected on the
operational and system design to achieve optimum operating condition. The optimal design
configuration of both affecting factors said at suitable operation is required to be evaluated as well,
which relies on the effective treatment (aiming for the required water quality/ contaminant removal)
and at the lowest overall cost. The issue of the ability in providing a system that moveable water
treatment which can be easily transported and relocated for off-site water treatment operation or
during water emergencies and may be extended for water reuse application especially at rural or
island users would be beneficial to be explored.

In spite of other type of membrane processes, this paper focuses on ultrafiltration membrane process.
Ultrafiltration has been recognized as one of the most applied process in water treatment system due
to its low pressure process thus requiring less energy and has less economic cost. Therefore, to identify filtration performance from this process concentrating on the hollow fiber membrane application, it is best to understand and analyse the factors that may affect the performance of the ultrafiltration hollow fiber membrane; which is reviewed in this paper.

MEMBRANE PROCESSES

Membrane processes are categorized based on the driving force such as pressure (Drioli and Macedonio, 2012), temperature and osmotic differences across the membrane (Mukiibi and Feathers, 2009; Fane et al., 2011; Peter-Varbanets et al., 2009). In the water treatment especially for drinking water purposes, pressure-driven membranes are used (Bruggen et al., 2003). The pressure-driven membranes are categorized into four classes according to the separation process, namely, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The two former are low pressure processes (Guo et al., 2010) while the latters are high pressure processes. Table 1 below summarized (Ozaki, 2004, Bruggen et al., 2003; Baker, 2004; Fane et al., 2008).

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Microfiltration (MF)</th>
<th>Ultrafiltration (UF)</th>
<th>Nanofiltration (NF)</th>
<th>Reverse Osmosis (RO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pore size</td>
<td>10nm~1μm</td>
<td>3~10nm</td>
<td>2~5nm</td>
<td>Not detectable</td>
</tr>
<tr>
<td>Retain particulates (MW)</td>
<td>&gt;300,000</td>
<td>1,000~300,000</td>
<td>&gt;150</td>
<td>&lt;350</td>
</tr>
<tr>
<td>Applied pressure</td>
<td>0.005~0.2 MPa</td>
<td>0.01~0.3 MPa</td>
<td>0.3~1.5 MPa</td>
<td>1~10MPa</td>
</tr>
<tr>
<td>Main applications</td>
<td>Removal of particles and bacteria, pre-treatment for RO and UF</td>
<td>Drinking water production, fruit juice clarification, home water purifiers</td>
<td>Removal of micropollutants, desalination of brackish water, concentration of chemicals</td>
<td>Desalination of brackish and seawater. Production of ultrapure water.</td>
</tr>
</tbody>
</table>

Based on its contaminant removal efficiency, Mierzwa et al. (2008) had proven that UF membrane has a high potential drinking water. This is statement has been supported by Guo et al. (2010) and Peter-Varbanets et al. (2010).
As mentioned previously, there are many advantages that favours membrane processes over the conventional methods. The tabulated advantages and disadvantages of membrane processes are given in Table 2.

**Table 2 Advantages and Disadvantages of Membrane Process**

<table>
<thead>
<tr>
<th>Membrane process application</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td></td>
</tr>
<tr>
<td>• Superior and consistent high quality permeate water</td>
<td>Nakatsuka et al., 1996; Bodzek and Konieczny, 1998a; Rahman et al., 2008; Guo et al., 2009; Rahman et al., 2012</td>
</tr>
<tr>
<td>• Capable of removing wider range of substances</td>
<td></td>
</tr>
<tr>
<td>• Easy automation (operation) and maintenance</td>
<td></td>
</tr>
<tr>
<td>• Less or no usage of chemicals</td>
<td></td>
</tr>
<tr>
<td>• Much compacted system (33% less space occupied)</td>
<td></td>
</tr>
<tr>
<td>• Low energy requirements (microfiltration and ultrafiltration)</td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td></td>
</tr>
<tr>
<td>• Membrane fouling</td>
<td>Nakatsuka et al., 1996; Lenntech, 2011</td>
</tr>
<tr>
<td>• Membrane integrity failure</td>
<td>Childress et al., (2005)</td>
</tr>
<tr>
<td>• chemical corrosion such as oxidation</td>
<td>Guo et al. (2010)</td>
</tr>
<tr>
<td>• faulty installation and maintenance</td>
<td></td>
</tr>
<tr>
<td>• membrane stress and strain from operating conditions, such as backwashing or excessive movement due to vigorous bubbling</td>
<td></td>
</tr>
<tr>
<td>• Damage by sharp objects not removed by pre-treatment.</td>
<td></td>
</tr>
</tbody>
</table>

The utmost limitation for membrane is fouling (Nakatsuka et al., 1996; Lenntech, 2011). From the Water and Wastewater Engineering book by Davis (2010), fouling is defined as the gradual decrease in permeate water flux at constant pressure. While fouling is a problem for membrane processes because it lessens the performance, thus the productivity of the membrane (Nicolaisen, 2002). Vos at al. (1998) stated that fouling such as rapid fouling has causes unstable flux of the membrane to the point that the water recovery to be less than 80%. Peter-Varbanets et al. (2010) mentioned how fouling can occur; due to membrane adsorption (membrane hydrophobicity), pore blocking, cake layer formation (Nicolaisen, 2002) and precipitation or biofilm formation (bio fouling). Nicolaisen (2002) added particles in raw water as the fouling source.

Other limitation of membrane is membrane integrity failure. This is crucial for hollow fiber membranes that are self-supporting. Childress et al. (2005) has given an example; when high pressure is applied to a hollow fiber membrane with low modulus of elasticity, the fiber may break because it is unable to withstand the pressure. All the advantages and disadvantages mentioned and discussed
above may also be dependent on the type of membrane configuration used in the system as shown in Table 3 (Bolog, (2009b)).

**Table 3 Polymeric membrane configurations (advantages and disadvantages)**

<table>
<thead>
<tr>
<th>Configuration (Area: Volume (m² : m³))</th>
<th>Packing Density</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate and frame (also known as flat sheet) (400 – 600)</td>
<td>Moderate</td>
<td>Can be dismantled for cleaning</td>
<td>Complicated design Cannot be backwash and high cost</td>
</tr>
<tr>
<td>Spiral wound (800 – 1,000)</td>
<td>High</td>
<td>Low energy cost, robust and compact, low cost fabrication</td>
<td>Not easily cleaned – cannot be backwashed, poor handling solids</td>
</tr>
<tr>
<td>Tubular (20 – 30)</td>
<td>Low</td>
<td>Easily mechanically cleaned, good solid handling, tolerant of high suspended solid</td>
<td>High capital and membrane replacement cost</td>
</tr>
<tr>
<td>Hollow fiber (5,000 – 40,000)</td>
<td>Very high</td>
<td>Can be backwashed, compact design, tolerant to high colloidal levels</td>
<td>Sensitive to pressure shocks</td>
</tr>
</tbody>
</table>

**APPLICATION OF ULTRAFILTRATION MEMBRANE IN ‘MOVABLE’ WATER TREATMENT SYSTEM**

As mentioned in earlier section, ultrafiltration is has been recognized as one of the most applied process in water treatment system. It provides an absolute barrier to particles, bacteria, high molecular weight organic molecules, emulsified oils and colloids. Removal of chlorine-resistant pathogens and their spores, such as *Cryptosporidium* from water supply is also possible (Kajitvichyanukul et al., 2011).

Since the focus of this paper is primarily on ultrafiltration process, specifically on easily-transport water treatment system; Table 4 simplifies several examples of applications of ultrafiltration membrane in water treatment in the past years. Included is an inorganic (non-polymeric) membrane which is ceramic. From the table, it can be seen that the efficiency of membrane ultrafiltration is very good. From water treatment plant to portable water treatment device, the membrane filtration system works properly and has high contaminants removal efficiency. Commercial portable water filters that apply membrane as its filtering media are also included. These commercial portable water filters (Katadyn Mini Ceramic, Sawyer PointONE™ Filter and LifeStraw®) have been regularly used and
received many good reviews from its users (eartheasy, 2011; thebackpacker.com, 2011; HikeLighter, 2012).

Table 4 Membrane application in water treatment (movable and easily transport) system

<table>
<thead>
<tr>
<th>Types of water treatment system</th>
<th>Membrane used</th>
<th>Removal efficiency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>UF membrane filtration</td>
<td>Cellulose acetate Hollow fiber membrane (MWCO &gt;150kDa)</td>
<td>Turbidity: 100% TOC: 100% E. Coli: 100% Fe: 98.9% Mn: 77.8%</td>
<td>(Oe et al., 1996)</td>
</tr>
<tr>
<td>Katadyn Mini Ceramic&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.2 μm ceramic Ag-impregnated</td>
<td>1.7 – 4.9 LRV*</td>
<td>(Katadyn, 2011; Loo et al., 2012)</td>
</tr>
<tr>
<td>Sawyer PointONE™ Filter&lt;sup&gt;a&lt;/sup&gt;</td>
<td>U-shaped 0.1 Micron Absolute Micron Hollow Fiber Membrane</td>
<td>Protozoan parasites: &gt;99.99% Bacteria: &gt;99.99%</td>
<td>(Sawyer, 2005)</td>
</tr>
<tr>
<td>Mobile water maker</td>
<td>40 nm Ceramic Tubular</td>
<td>Turbidity: &gt;99.8% TOC: 31.5% E. Coli: &gt;99.8% Fe: &gt;99.3% Mn: &gt;99.3%</td>
<td>(Groendijk and de Vries, 2009)</td>
</tr>
<tr>
<td>Direct drinking water</td>
<td>Thin Film Spiral wound (MWCO 3.5 kDa)</td>
<td>Turbidity: 94.96% TOC: 85.27% E. Coli: 100% Fe: 50% Mn: 50%</td>
<td>(Mierzwa et al., 2008)</td>
</tr>
<tr>
<td>AQUAPOT</td>
<td>Polyethersulfone (PES) hollow fiber (MWCO 150 kDa), Polysulfone (PS) spiral wound (MWCO 100 kDa)</td>
<td>Turbidity: 53.6% Total Coliforms: 100% Thermotolerants Coliforms: 100% Colour(average): 39.5%</td>
<td>(Arnal et al., 2001); (Arnal et al., 2008); (Arnal et al., 2010)</td>
</tr>
<tr>
<td>LifeStraw®&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20 nm UF hollow fiber membrane</td>
<td>Turbidity: 53.6% E. Coli: 7.3 LRV Cryptosporidium: 3.9 LRV</td>
<td>(VestergaardFrandsen, 2010)</td>
</tr>
<tr>
<td>Transportable UF system</td>
<td>4 modules (18 m&lt;sup&gt;2&lt;/sup&gt;) of UF hollow fiber (MWCO 100 kDa)</td>
<td>N/A</td>
<td>(Barbot et al., 2009)</td>
</tr>
<tr>
<td>Enhanced Surface Water Treatment</td>
<td>Three 8 × 40” hollow fiber membrane UF modules</td>
<td>Turbidity: ~99.9% Iron: ~99.9% Phosphate: 66.7%</td>
<td>(Hofman et al., 1998)</td>
</tr>
<tr>
<td>UF for surface water</td>
<td>Polyvinyl chloride (PVC) hollow fiber membrane (MWCO 80 kDa)</td>
<td>Turbidity: 100% Bacteria: 100% Coliform: 100% Natural Organic Matter: 20 – 40 %</td>
<td>(Guo et al., 2009)</td>
</tr>
</tbody>
</table>

<sup>a</sup>refers to commercial portable water filters that are available in the market.

LRV is log removal value

N/A: information not available
For UF water treatment application, hollow fiber is the most commonly used membrane configuration (Kennedy et al., 2008) and it is also shown from Table 4. Furthermore, Mierzwa et al. (2008) found that the required pressure for maintaining a certain flux for hollow fiber membrane is much lower than that for spiral wound membrane.

**FACTORS AFFECTING THE PERFORMANCE OF HOLLOW FIBER MEMBRANE IN WATER TREATMENT SYSTEM**

The performance of hollow fiber membrane as the filter media in water treatment system can be influenced by several factors. Generally, the factors may be classified as shown in Figure 1 (Bulong, 2009b).

**Factors influencing pollutants separation in membrane process**

- Physical-chemical properties of the compound
  - Molecular size
  - Solubility
  - Diffusivity
  - Polarity
  - Hydrophobicity
  - Compound

- Membrane properties
  - Permeability
  - Pore size
  - Hydrophobicity
  - Surface charge

- Membrane operating conditions
  - Flux
  - Transmembrane pressure
  - Rejections/recovery
  - Raw water quality

**Figure 1 Factors influencing in membrane separation performance (adapted from: Bolong 2009a)**

However in this paper, factors such as membrane material (polymer), permeate flux and transmembrane pressure, pre-treatment of raw water before membrane filtration, backwashing and chemical cleaning; were highlighted in this paper as they are the operating conditions that can be set before the operation of membrane filtration system.
Membrane material (polymer)

Hollow fiber membranes mostly are made of polymeric materials due to ease of fabrication. UF membranes are usually prepared by phase-inversion process and have an asymmetric porous structure (Fane et al., 2008). Most common polymers used are cellulose acetate (CA), polysulfone (PS), polyether sulfone (PES), polyvinylidenedifluoride (PVDF) and polyacrylonitrile (PAN) (Wagner, 2001; Fane et al., 2008). Choosing the right material is essential and dependent on the applications and the operating conditions of the hollow fiber membrane. During the first decades of membrane, CA was the main membrane material. But having low chemical and thermal stabilities as well as narrow pH tolerance range had it substituted with other polymers (or sometimes polymer blends) to produce UF membranes (Fane et al., 2008). These polymers such as PS and PVDF have wider range of pH and resistant to temperature and chlorine attack.

Guo et al. (2009) used polyvinylchloride (PVC) as the polymer for the hollow fiber membrane that was used in surface water treatment (as shown in Table 1). An advantage of PVC membrane is its resistant to free chlorine compared to the common polysulfone membrane. This advantage is important in terms of chemical cleaning because it can reduce membrane biofouling phenomena.

Nakatsuka et al. (1996) had shown in their study the comparison between two hollow fiber membranes, same configuration but with different polymer. The study resulted on the CA membrane had higher fouling resistance that PES membrane, thus making it easier to be backwashed. This was due to the hydrophilic characteristic of CA membrane while PES membrane is hydrophobic. Therefore, Nakatsuka et al. (1996) concluded that UF hollow fiber membrane water treatment performance is strongly depending on the membrane polymer. This is supported by Bodzek and Konieczny (1998b) that found that the removal efficiency of a membrane is depending on the membrane’s polymer. This is because the hydrophobicity characteristic of the polymer will affect the water contact between the membrane and the raw water. The higher the hydrophobicity of membrane, the higher will the fouling tendency of the membrane is.
Therefore, membrane material (polymer or polymer blends) is important to determine the membrane resistant to fouling. The membrane material will also determine whether the membrane can be chemically clean by its range of chemical resistant characteristic or not.

**Permeate flux and Transmembrane Pressure**

According to Kennedy et al. (2008), membrane filtration system for water treatment can be operated either in:

- (a) constant permeate flux with varying pressure or
- (b) constant transmembrane pressure with varying flux.

Permeate flux is the permeate flow rate per unit membrane area. While transmembrane pressure (TMP) is the driving force for the flux.

In discussing the close relationship between permeate flux and transmembrane pressure (TMP), Xia et al., (2004) stated that the permeate flux increases linearly with TMP when the TMP is less than 0.12MPa and up until the permeate flux is approximately 145 L/m²h. It is Darcy’s law region in which the membrane permeability limits the permeate flux. The study found that the deviation from the linear relationship is the UF region, where permeate flux did not depend on membrane resistance but limited by the mass transfer condition in the boundary layer.

Since permeate flux is linear with TMP, the case can be vice versa as long as both are in the Darcy’s law region. This is proven by a study conducted by Guo et al. (2009) where two constant permeate fluxes which are 60 L/m²h and 100 L/m²h were compared. The study shown that when the permeate flux increases, TMP also increases. This is true, based on permeate flux-TMP relationship stated by Xia et al. (2004) previously since the fluxes (60 L/m²h and 100 L/m²h) are still in the Darcy’s law region. However, there is an obvious difference in the increase of the TMP for both fluxes as observed by Guo et al. (2009) in their study, where TMP for lower permeate flux (60 L/m²h) is much more stable compared to that of the higher flux (100 L/m²h). The increase of TMP is not a very good condition since it indicates increase of membrane fouling (Crozes et al., 1997; Guo et al., 2009). Therefore Guo et al. (2009) concluded that the operation of higher constant permeate flux is less stable compared to the lower one.
Permeate flux and transmembrane pressure (TMP) are correlated to each other. Either the membrane filtration system is operated in constant permeate flux or constant TMP, it is recommended to keep both in the Darcy’s law region i.e. permeate flux below 145 L/m²h or TMP below 0.12MPa. This is to avoid membrane fouling, especially when the TMP is high.

**Pre-treatment**

In a membrane system, pre-treatment is recommended to control fouling (Guo et al., 2009). Pre-treatment is optional to be added in any membrane filtration system since membrane processes are able to treat water within a single operation (Bodzek and Konieczny, 1998). For the case of hollow fiber membrane that can be automatically backwashed with permeate water, extensive pre-treatment requirement reduces (Kennedy et al., 2008). However, it does not mean that pre-treatment is absolutely not required in the membrane filtration system. Nicolaisen (2002) and Kennedy et al. (2008) suggested that adequate pre-treatment of the raw water is mandatory for a well-functioning membrane plant.

The effectiveness and necessity of the pre-treatment depends on the raw water quality. Most of the time, pre-treatment as simple as sand filter is added to the water treatment system to filter large particles and suspended solids. This action can actually help lengthening the membrane life because large particles can cause damage to the membrane.

For UF membranes, it is good to have pre-treatment especially when the raw water contains contaminant such as manganese. For example, Vos et al. (1998) reported that manganese in the raw water could not be filtered by the UF hollow fiber membrane at first because it would change into its ionic form, thus passing through UF. Then, Vos et al. (1998) modified their water treatment system by adding pre-treatment before the UF unit. The pre-treatment chosen was oxidation by potassium permanganate (KMnO₄) where the manganese ions were oxidized. This pre-oxidation process increases the manganese removal in the raw water by approximately 73%.

Guo et al.(2009) had shown the effects of pre-treatment to the hollow fiber membrane performance in water treatment indicating that between the two membrane filtration systems performed; first with Y-style filter (of 500 μm pore size) only and second with Y-style filter plus coagulation agents and bag-
style filter. The former only sieve contaminants’ particles that were larger than its pore size. However, over the time, the retained particles form a cake layer thus causes clogging that reduces the permeate flux. Furthermore, filtered particles (especially natural organic matter) can adhere to the internal surfaces of the membrane which causes irreversible fouling. This is responded by sharp increase of transmembrane pressure from 0.7 to 1.0 bar. On the other hand, when combined pre-treatment were used, coagulation agents helped to combine those fine particles before entering the membrane and then making it easier for the UF membrane to retain it.

Pre-treatment may be optional but it is still a big help to the membrane filtration system, especially when the raw water contains large particles that could cause damage to the membrane.

**Backwashing**

It is been known that fouling is the major limitation for membrane. In order to overcome this limitation, membrane will be backwash or clean between intervals during the filtration process (Pervov et al., 1996; Hofman et al., 1998; Davis, 2010). The backwashing pressure will usually be twice (Nakatsuka et al., 1996) or thrice (Hofman et al., 1998) the permeate flux. Backwash for hollow fiber membrane can be carried out by changing the permeate water flow direction (Kennedy et al., 2008). By that, the reverse flow washes out the foulants that formed cake layer on the membrane surface during the filtration process.

The backwash interval between two filtration processes plays role in limiting the effect of fouling during membrane filtration operation. In the study of drinking water treatment using ultrafiltration hollow fiber membrane (Nakatsuka et al., 1996; Kennedy et al., 2008), it was found that the longer the backwash interval, the more severe is the fouling. If consistently disregarded, the fouling can be irreversible which would be much difficult to be removed.

The backwash frequency also plays an important role during the operation of membrane filtration system in water treatment. Crozes et al. (1997) made a comparison of two backwash frequency on membrane resistance to fouling. It was deduced that as the backwash frequency increases, TMP increase can be reduced. As mentioned earlier, increase of TMP indicates the increase of fouling. So, by reducing the increase of TMP in the filtration process, the membrane fouling can be reduced.
Backwash should not be rigid. It has to be adaptable to the raw water composition especially in the period of rainfall (Hofman et al., 1998) when there will be rapid variations of contaminants. This is because the concentration of contaminants in the raw water can affect the backwash efficiency.

Backwashing is essential for any membrane filtration system to avoid membrane fouling turning into an irreversible fouling. In deciding the optimal conditions for backwashing, it is important to note the backwash interval, backwash frequency and the raw water quality throughout the operation of the membrane filtration system in the water treatment system.

**Chemical cleaning**

Backwash alone is not sufficient to remove fouling particles on the surface of the membrane. Therefore, cleaning using chemicals that is more rigorous may be required (Davis, 2010). Chemical cleaning can be applied to restore the membrane’s initial performance (Shengji et al., 2008; Chen et al., 2008) and the increase of the reducing flux (due to fouling) after the cleaning indicates the cleaning efficiency.

Oe et al. (1996) found that transmembrane pressure returned to its initial value and remained unchanged after chemical cleaning of 5% citric acid solution circulated through the membrane module. The chemicals used for the cleaning process depends on the raw water compositions. This is because the chemical cleaning process must be able to remove the contaminants sticking on the membrane surface that causes fouling. As mentioned in earlier section about membrane materials, it is important to note the type of polymer that is used for the membrane. This is to avoid chemical attack such as corrosion if the membrane polymer is not resistant enough to chemical.

Just like pre-treatment, chemical cleaning might be optional. But it is still a better option to have it especially when the raw water quality is very low and backwashing is not sufficient to return permeate flux or TMP.

**CONCLUSIONS**

The application of membrane processes in water treatment system particularly for easy-movable system are getting more attention due to its advantages over conventional methods and is more suitable for off-site water treatment operation or during water emergencies. It may also be extended
for water use application especially for rural or island users. For water treatment system such as drinking water treatment, ultrafiltration hollow fiber membrane is a very good choice to be applied in the water treatment. To get the most from the membrane operation, it is important to look into factors that have influence on the membrane’s performance. As discussed in this review paper, membrane material, permeate flux and transmembrane pressure (TMP) and backwashing are factors that can affect the performance of ultrafiltration hollow fiber membrane in water treatment application. Pre-treatment and chemical cleaning though optional can still be a great help to increase the filtration performance of the membrane. The review is hoped to be beneficial in deciding the optimal conditions for ultrafiltration hollow fiber membrane in water treatment system.

REFERENCES


