ISSN 2355-8776

Purification of Raw Water from Pollutant using Coupling Membrane Filtration to UV Irradiation: Preliminary Study

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ARTICLE INFO

Article history
Received November 11, 2022
Revised January 13, 2023
Accepted January 21, 2023

Keywords
Drinking water
Membrane
Microfiltration
Pollutant
UV irradiation

ABSTRACT

The low quality of groundwater, along with the increasing demand for drinking water for the community, encourages the need for water treatment technology to produce quality drinking water that is environmentally friendly. One promising method to be applied is membrane technology. In water treatment systems, membrane technology is often not used alone but combined with other methods to improve water quality more effectively. This study aims to apply several methods for the raw water treatment system to drinking water, including membrane filtration and UV irradiation. The removal of chemical pollutants was investigated and compared to the standard value from Minister of Health Regulation No. 492 Year 2010 for drinking water quality. This coupled treatment successfully improved the water quality. The concentration of chemical and biological pollutants such as total dissolved solids (TDS), Fe, Zn, Pb, and total Coliform were reduced by 58.53%; 43.48%; 88.89%; 66.67%.; and 86.15%, respectively. The results indicate that coupling microfiltration membrane to UV irradiation method can be an effective treatment to remove chemical pollutants and enhance the quality of raw water for drinking water preparation.

1. Introduction

Water is one of the basic needs of human life. It is required primarily for drinking, hygiene, and sanitation. UN's Sustainable Development Goals 6 (SDGs 6) explicitly mentions that safe drinking water and sanitation for all must be ensured [1]. One of the problems experienced by people living in big cities is a decrease in the quality of raw water for drinking water purposes. Raw water is a water source that is processed into drinking water. It comes from surface water, groundwater basins, and rainwater. Unfortunately, groundwater or river water quality in several areas in Indonesia still does not meet the requirements of healthy and drinkable water. One of the causes is water pollution due to human activities such as household waste and wastewater from various industrial activities. This condition can be dangerous because consuming poor-quality water causes health problems for the community, either directly or indirectly [2].

The higher level of water pollution causes the need for disinfection to increase, which leads to the higher costs required for drinking water treatment. On the other hand, the demand for drinking water is also increasing along with the faster population growth, especially in Indonesia. Thus, alternative technology should be provided to overcome this challenge. One of the technologies developed as an alternative method to increase the effectiveness of the water treatment process is membrane technology. Membrane is a thin layer between two phases (feed and permeate) that can separate particles of different sizes [3], [4]. Generally, membrane technology is divided into four (4) filtering groups which are distinguished based on the size of the separated particles: (a) microfiltration (MF), (b) ultrafiltration (UF), (c) nanofiltration (NF), and (d) reverse osmosis (RO). Membrane processes are widely used in water treatment and reuse applications. It has been known as an effective method for removing pollutants from water and various wastewater [5], [6].

The application of membrane technology in the water treatment process provides several advantages. This method is environmentally friendly because membrane technology can reduce the content of polluting particles in water without using chemicals as in conventional water treatment processes [7]. In conventional water treatment systems, the coagulation-flocculation stage requires chemicals in the form of coagulants and flocculants, which will also be produced as by-products at the end of the process, which will generally be discharged into the environment. In addition, the installation of membrane technology is also compact and straightforward, so the area required for the water treatment process is smaller [8], [9].

In water treatment system, membrane technology is often not used alone but combined with other methods to improve water quality more effectively. In general, before the filtration process using a membrane is carried out, it must first be preceded by a mechanical filtration process so that larger particles of impurities can be removed, including pesticides, ammonia, and pathogenic bacteria. In addition, the combination of membrane technology with ultraviolet (UV) irradiation is recommended to inactivate microorganisms in water [10], [11]. Disinfection using an ultraviolet (UV) lamp has many advantages over other conventional chemical disinfection methods, such as chlorination or ozonation. Chemical disinfectants produce by-products that are toxic and dangerous for human health like bromate and chlorite [12]. UV sterilization also has benefits for drinking water system, for example: (i) the water quality such as total organic carbon, pH, and turbidity would not be altered, (ii) relatively inexpensive, (iii) easy and fast to operate [13], [14].

This study aims to apply coupling method of MF membrane and UV irradiation for treating raw water into drinking water. The ability and effectiveness of this method would be determined and examined by the quality of water produced and the pollutants removal. The quality of the water produced is targeted to meet the requirements from Minister of Health Regulation No. 492 Year 2010 for drinking water.

2. Research Methodology

2.1. Design of Raw Water Treatment Unit

A schematic of the coupling membrane filtration-UV irradiation water treatment system is shown in Fig. 1. The system was composed of three stages of water treatment: (i) mechanic filtration, (ii) microfiltration membrane, and (iii) UV irradiation. In the first stage of treatment, feed water was filtered through slow sand filtration (SSF) to pre-clean raw water from particulates. The second stage was filtration using microfiltration (MF) membrane. The final effluent was disinfected using UV lamp.

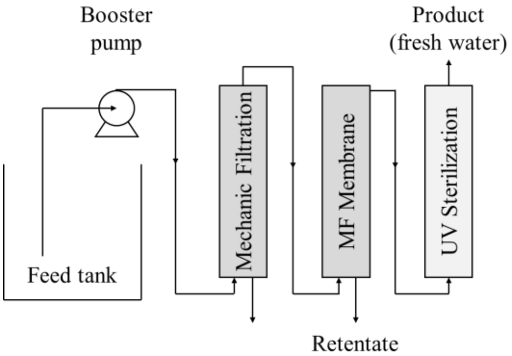

Fig. 1. Schematic diagram of raw water treatment system

2.2. Samples and Sampling Point

Tap water from Bioprocess and Environmental Laboratory Universitas Ahmad Dahlan was used to test the performance of water treatment unit. Sample was taken only from one sampling point as the scale of this research is limited as preliminary study to investigate the early performance of coupling membrane filtration-UV irradiation unit system. The water sample was put into a feed tank with capacity of 5 L, while fresh water produced was collected after the last stages.

2.3. Drinking Water Treatment Procedure

All experiments were carried out at constant feed pressure of 3 bar using booster pump. The maximum flow rate through the coupling system was 1 L/min (0.264 gpm). From the feed tank, a booster pump was used to distribute feed water into SSF at the first stage. The SSF used different media consisting of silica sand, manganese sand, anthracite, and zeolite to remove large particles that could damage the membrane. The next stage was MF membrane. This crossflow MF treatment consisted of two spiral wound module cartridges. In the last stages, the feed water was sterilized using a 12 W UV lamp 254 nm. The final product was collected and taken for laboratory analysis.

2.4. Analytical Measurements

The standard analytical procedure for water analysis to examine the physical, chemical, and biological parameters from the feed (raw water) and product (fresh water produced) are listed in Table 1. Laboratory analysis for the water samples were conducted in Balai Laboratorium Kesehatan dan Kalibrasi Dinas Kesehatan Yogyakarta.

Table 1. Standard analytical procedure for water analysis in this study

Analytical parameters	Unit	Method specification
Odour/Taste	-	Organoleptic
Colour	TCU	IKM/5.4.24/BLKK-Y
Total dissolved solids (TDS)	mg/L	Potentiometry
Turbidity	-	SNI 06-6989, 25-2005
pH	-	SNI 06-6989, 11-2004
Hardness ($CaCO_3$)	mg/L	APHA 23rd Edition, 2340-C, 2017
Iron (Fe)	mg/L	IKM/5.4.1/BLKK-Y
Manganese (Mn)	mg/L	APHA 23rd Edition, 3500 Mn-B, 2017
Zinc (Zn)	mg/L	APHA 23rd Edition, 3111-B, 2017
Sulphate (SO_4)	mg/L	APHA 23rd Edition, 4500 SO_4^- E, 2017
Lead (Pb)	mg/L	APHA 23rd Edition, 3111-B, 2017
Organics ($KMnO_4$)	mg/L	Titrimetry
Mercury (Hg)	mg/L	Mercury analyzer
Detergent	mg/L	Spectrophotometry
Fluoride (F)	mg/L	SNI 06-6989, 29-2005
Total *Coliform*	MPN/100 mL	IKM/5.4.1.M/BLKK-Y

The effectiveness of water treatment system was defined as removal percentage calculated in Equation 1:

$$Removal\ (\%) = \left(\frac{C_{feed} - C_{product}}{C_{feed}}\right) \times 100\% \quad (1)$$

where C_{feed} and $C_{product}$ are concentration of specific parameter of the water as listed in Table 1 before and after treatment, respectively.

Results from the analysis measurement were then compared to the standard requirements for hygiene-sanitation water (Minister of Health Regulation No. 32 Year 2017) and drinking water (Minister of Health Regulation No. 492 Year 2010) [15], [16].

3. Results and Discussion

3.1. Water Treatment System Evaluation

The goal of the treatment was to develop an affordable and environmentally friendly method to produce water that has parameters close to the drinking water standards in Indonesia. The performance of water purification methods in this study was experimentally investigated from the concentration of physical, chemical, and biological pollutants from water before and after treatment as listed in Table 2. Meanwhile Fig. 2 shows the percentage removal of each parameter in the water after being purified using coupling MF membrane-UV irradiation.

Table 2. Concentration of each parameter in the water before and after being treated using coupling MF membrane-UV irradiation

Parameter	Unit	Before MF + UV	After MF + UV
Total dissolved solids	mg/L	463	192
Turbidity	-	1.73	0.67
pH	-	7.85	8.16
Hardness ($CaCO_3$)	mg/L	151.72	128.08
Iron (Fe)	mg/L	0.23	0.13
Manganese (Mn)	mg/L	0.05	0.04
Zinc (Zn)	mg/L	0.09	0.01
Sulphate (SO_4)	mg/L	42.67	31.196
Lead (Pb)	mg/L	0.03	0.01
Organics ($KMnO_4$)	mg/L	3.65	2.18
Mercury (Hg)	mg/L	<0.001	<0.001
Detergent	mg/L	< 0.002	< 0.002
Fluoride (F)	mg/L	0.15	0.02
Total *Coliform*	MPN/ 100 ml	13	1.8

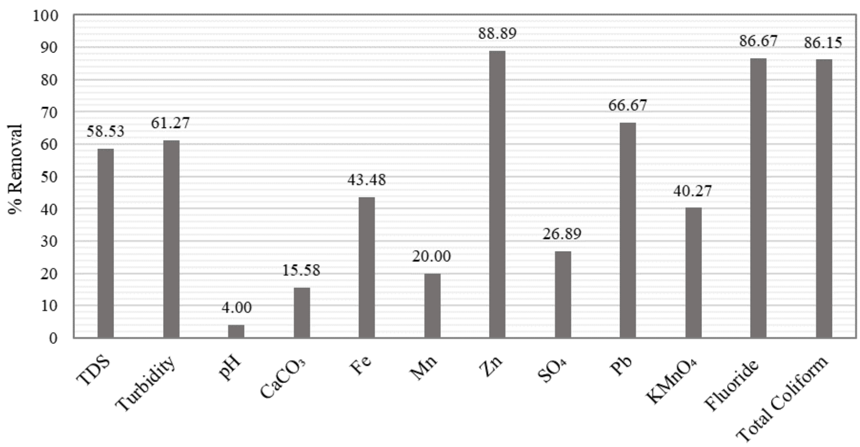

Fig. 2. Removal percentage of physical, chemical, and biological parameters in produced water (after treatment using MF + UV)

Overall, the removal effectiveness of physical, chemical, and biological pollutants in the water was varied. Table 2 indicates that the pH of fresh water (after treatment) was higher than before treatment, which means that raw water was more acidic than the treated water. This condition can be caused due to the presence of natural organic matter (NOM) in raw water. NOM has been known as substances that reduce the quality of water because of its carrier properties for many pollutants in water, particularly drinking water [17], [18]. The presence of NOM in surface water is majority in the form of humic substances, group of weak acidic electrolytes which affect color and odor from the water [19]. After being treated using MF-UV system, the concentration of these substances decreased. Thus, the pH of produced water increased.

Fig. 2 shows that the lowest removal from physical, chemical, and biological parameters was pH (4.00%), while the highest removal was zinc (88.89%). It indicates that this coupling system was effective for retaining physical, chemical, and biological pollutants in raw water. The first stage in this water treatment unit, mechanic filtration by SSF, is a pretreatment method for pre-cleaning the feed water before being distributed into MF membrane and UV irradiation unit. Second stage was MF membrane followed by UV sterilization in the last stage to produce fresh water.

Experimental results show that the combination of MF membrane and UV irradiation system was able to remove physical contaminants such as total dissolved solids (TDS) and turbidity of raw water. As much as 58.53% TDS in the final effluent was retained and the turbidity reduction reached 61.27%. In addition, the organics in the produced water (represented by $KMnO_4$) also decreased by 40.27%. It indicates that membrane treatment efficiently removes organic pollutants detected in water samples [20].

In the case of biological parameter, coupling method of MF-UV achieved high reduction of total *Coliform*, which was 86.15%. MF membrane has pore size of 0.1 µm [18]. This number is much smaller than the *Coliform* bacteria. It indicates that MF membrane effectively blocked total *Coliform* bacteria in water samples. Conducting coupling strategy of MF membrane and UV irradiation in this study provided high removal of total *Coliform*. This results is in accordance with prior studies that reported membrane system successfully removed pathogens from water samples [21], [22].

The removal of inorganic substances such as iron (Fe), manganese (Mn), zinc (Zn), lead (Pb), and fluoride (F) in water samples were also evaluated. As shown in Fig. 2, the coupling method was effectively removed more than 40% for particular chemical pollutants, such as Fe (43.48%), Zn (88.89%), Pb (66.67%), and F (86.67%).

3.2. Product Water Quality

The water quality parameters before and after treatment are represented in Table 3. It shows the comparison of analyzed parameters of raw water along with the mandatory standards established in Indonesia for drinking water and hygiene water based on Minister of Health Regulation No. 32 Year 2017 and Minister of Health Regulation No. 492 Year 2010, respectively.

The results show that the coupling method of MF membrane and UV irradiation improved the quality of the effluents. Considerable reductions in physical parameters such as TDS and turbidity were observed. Chemical pollutants, especially organic and inorganic substances in water samples, were also significantly reduced to low levels. Regarding chemical parameters such as heavy metals (Fe, Mn, Zn, Pb, Hg), the fresh water produced already met the mandatory standards for both requirements.

Table 3. Comparison of the qualities of raw water, fresh water produced, and the requirements for drinking water and hygiene-sanitation water

Analytical parameters	**Unit**	**Raw water (Before treatment)**	**Fresh water produced (After treatment)**	**Drinking water requirements (Permenkes No. 492 Th. 2010)**	**Hygiene water requirements (Permenkes No. 32 Th. 2017)**
Physical parameter					
Odour/Taste	-	No Odour/ No Taste	No Odour/ No Taste	No Odour/ No Taste	No Odour/ No Taste
Colour	TCU	10	10	15	50
Total dissolved solids	mg/L	463	192	500	1000
Turbidity	-	1.73	0.67	5	25
Chemical parameter					
pH	-	7.85	8.16	6.5-8.5	6.5-8.5
Hardness ($CaCO_3$)	mg/L	151.72	128.08	500	500
Iron (Fe)	mg/L	0.23	0.13	0.3	1
Manganese (Mn)	mg/L	0.05	0.04	0.4	0.5
Zinc (Zn)	mg/L	0.09	0.01	3	15
Sulphate (SO_4)	mg/L	42.67	31.196	250	400
Lead (Pb)	mg/L	0.03	0.01	0.01	0.05
Organics ($KMnO_4$)	mg/L	3.65	2.18	10	10
Mercury (Hg)	mg/L	<0.001	<0.001	0.001	0.001
Detergent	mg/L	< 0.002	< 0.002	0.05	0.05
Fluoride (F)	mg/L	0.15	0.02	1.5	1.5
Microbiological parameter					
Total Coliform	MPN/ 100 ml	13	1.8	0	50

Based on Table 3, it is noticeable that the quality of raw water (before treatment) has already followed the Indonesia regulation for hygiene water requirements. However, in order to be able to be consumed further as drinking water, some parameters are not in compliance with the standards. In particular, the concentration of total dissolved solids/TDS (463 mg/L) was close to the threshold (500 mg/L), while the total Coliform (13 MPN/100 ml) was higher than the respective regulatory targets (0 MPN/100 ml). Consequently, further treatment specifically aimed at reducing these pollutants in the water was required.

4. Conclusion

This study shows an effective performance of coupling method of microfiltration membrane and UV irradiation for purification of raw water. The combination of these two stages showed an improvement of water quality. This treatment method resulted in high removal of chemical pollutants and heavy metals such as total dissolved solids (TDS), Fe, Zn, Pb, and total Coliform for 58.53%; 43.48%; 88.89%; 66.67%.; and 86.15%, respectively. Microfiltration played an essential role in the removal of chemical pollutants, while UV irradiation is recommended for water disinfection to reduce microbial pollutants. The results of physicochemical parameters match the requirements of Minister of Health Regulation No. 492 Year 2010 for drinking water quality. However, the microbiological parameter (total *Coliform*) from this result was still below requirements. Thus, further study needs to be conducted in order to improve the disinfection result and remove biological contaminant from the water.

Acknowledgment

This work was financially supported by Institute of Research and Community Service Universitas Ahmad Dahlan (LPPM UAD), Internal Research Grant Number PDP-069/SP3/LPPM-UAD/VII/2022.

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