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Fecal Coliforms and Total Coliforms Removal in Water Using Radio-Frequency (RF) Plasma System

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Abstract

A radio-frequency plasma system (RF) was used to investigate the removal of microorganisms from water. Plasma generated by RF radiation can produce active compounds (H•, •OH, H_2O_2, O_3, etc.) that have a high oxidation potential and can kill microorganisms present in water (fecal coliforms and total coliforms). The frequency of the plasma system was set to 3.0, 3.3 and 3.7 MHz and applied to river water for 60 minutes. The results show that in all runs, the pH of the water produced was in the range from 7.4 to 7.9. The removal efficiencies of fecal coliforms achieved were between 83.75 and 95% and were higher than the removal efficiencies of total coliforms, which were between 82.61 and 93.48%. Meanwhile, the death rate (k_D) of fecal coliforms wasfaster than that of total coliforms. Therefore, the removal of total coliforms is the key to removing microorganisms fromwater. RF plasma treatment can be used for treatment of drinking water to decrease microorganisms.

Keywords: radio-frequency, active compounds, microorganisms, water treatment

1. Introduction

Industrial, domestic and other activities can have a negative impact on water resources, such as causing a decrease in water quality. Such conditions can cause disruption, damage and danger to living organisms that depend on those water resources. Data from the National Development Planning Agency Indonesia in 2014 indicate that about 65-72% of contaminated wells were polluted by *Escherichia coli*. The bacteria come from toilets near the wells and even most of the rivers in Indonesia are contaminated by *Escherichia coli.* In Permenkes (Ministry of Health Regulation) 492 from 2010 about drinking water quality requirements it is determined that in water that will be used as drinking water, the total coliforms and fecal coliforms should be zero. Accordingly, research about the removal of microorganisms (fecal coliforms and total coliforms) from water is very important.

Water treatment using a plasma system is one of the ways to produce potable water in terms of health aspects. Plasma in water will generate active species, such as •OH, H•, O_3 and H_2O_2. These active species have a high oxidation potential and are able to kill microorganisms and degrade organic compounds in water (Sun et al., 1997). Another advantage of plasma systems is that they can produce ultraviolet light and shockwaves, which can also kill microorganismss in water (Robinson et al., 1973).

Over the last number of years, several researches have been done concerning the reduction of microorganisms in water using plasma systems (Joshi, 1995; Lukes, 2001; Aragi 2009; Desmiarti et al., 2013; Hazmi et al., 2013). Aragi (2009) examined removal efficiency of macroorganisms at 100% using a corona discharge to generate plasma in the treatment of drinking water. Studies have been devoted to the removal of microorganisms from drinking water by using a pulsed high voltage (Hazmi et al., 2013) or by using a dielectric barrier discharge (Desmiarti et al., 2013).The present research was conducted to investigate the capability of a radio-frequency (RF) plasma system to eliminate microorganisms from riverwater. Experiments were carried out in a batch system to see the effect of frequency on the removal of microorganisms (fecal coliforms and total coliforms). The quality of the water produced was compared with that of water produced by a drinking water refill station (DAMIU) in Padang City, West Sumatra, Indonesia.

2. Method

2.1 Water Source

Water samples were taken from the Kuranji River in Padang City, West Sumatra, Indonesia, on 15 April 2014 at 10:00 am under brightweather conditions. This river is one of the water sources for the Regional Water Utility Company (PDAM) in Padang City. The quality of the river water at the sampling time is shown in Table 1.

Table 1. Sample Quality

Water Quality Parameter	Unit	Sample
pH		7.27
Turbidity	NTU	67.6
TDS	mg/L	404
ORP	mV	-219.1
Temperature	°C	30.1
Fecal Coliforms	MPN/100mL	8,000
Total Coliforms	MPN/100mL	23,000

2.2 Experiment

The experimental set-up of the radio-frequency plasma system is diplayed in Figure 1.The water samples enter the plasma reactor, made of glass with a thickness of 2 mm and with a copper wire of 1 mm thickness and 30 cm length twisted around it. The electricity generated by the RF plasma generator is channeled through the copper wire to produce a dielectric discharge. This discharge dissociates the water molecules to generate active species thatare capable of killing microorganisms.

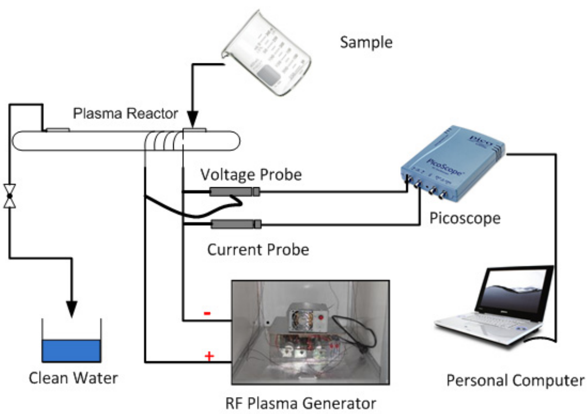


Figure 1. Experimental Set-up of Batch Radio-Frequency (RF) Plasma System

2.3 Analysis

The products were analyzed by examining the number of microorganisms (fecal coliforms and total coliforms). The procedure was executed with three different frequencies: 3.0, 3.3 and 3.7 MHz. Analysis of microorganisms (fecal coliforms and total coliforms) was conducted using the most probable number (MPN) method. The MPN method is a serial dilution test using a liquid medium, in this case brilliant green lactose bile 2% (BGLB) broth, in a test tube to obtain quantitative data about the presence of microorganisms in units of MPN/100mL.Analysis of water quality parameters was conducted by measuring pH, oxidation and reduction potential (ORP) of samples and products using Martini Instruments tools.

2.4 Death Rate Calculation

The death rate of microorganisms was calculated using the first order equation, as follows:

$$\frac{dN}{dt} = -kN \quad (1)$$

where N is the number of microorganisms (MPN/100mL), t is time (h), and *k* is microorganisms death constant

(h^{-1}). The k value was calculated by plotting the value of ln (N/N_0) versus t using the following equation:

$$ln\frac{\mathrm{N}}{\mathrm{No}} = -kt \quad (2)$$

With N_0 as the initial number of microorganisms.

3. Results

3.1Frequency Effect on Removal Efficiency (RE) of Microorganisms

The effect of the RF plasma system's frequency on the removal of microorganisms can be seen in Figure 2.

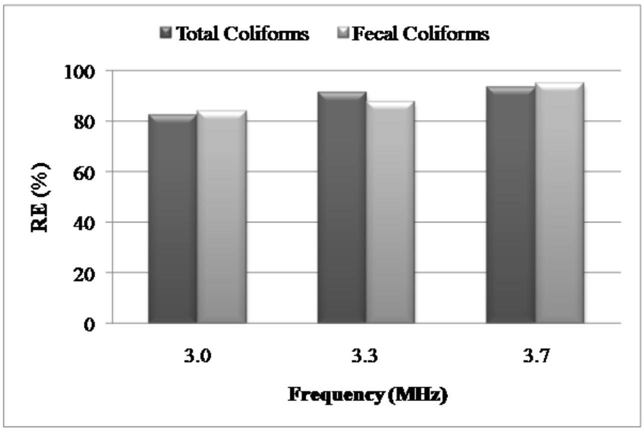
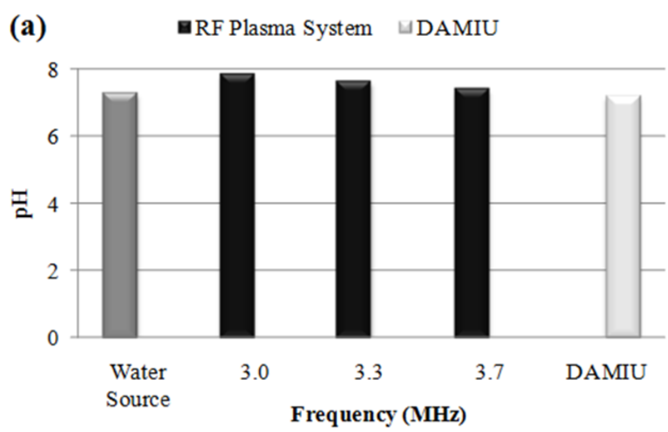


Figure 2. Frequency Effect on Microorganismss Removal

Based on Figure 2 the efficiency of microorganisms removal (fecal coliforms and total coliforms) increased along with the increase of the RF plasma system's frequency. A frequency of 3.0 MHz applied to the sample for 60 minutes could eliminate fecal coliforms and total coliforms by 83.75% and 82.61%. Meanwhile, at 3.3 MHz the removal efficiency of fecal coliforms and total coliforms increased to 87.5% and 91.3%, respectively. Increasing the frequency to 3.7 MHz gave a removal efficiency of fecal coliforms and total coliforms of 95.0% and 93.48%, respectively.

3.2 Frequency Effect on pH and ORP

The effect of frequency on pH and ORP can be seen in Figure 3.The results show that varying the frequency of the RF plasma system did not significantly affect pH. The pH values were in the range from 7.3 to7.9 – still within the quality standards (Figure 3a).An increase of the generated plasma frequency increased the value of ORP, as shown in Figure 3b. According to Suslow (2004), the ORP value indicates the system's ability to perform reduction and oxidation reactions and can be used to monitor the content of microorganismss in the water. The higher the water's ORP value, the more facile oxidation reactions proceed and the higher the amount of damaged cell membranes, so that the water quality increases.



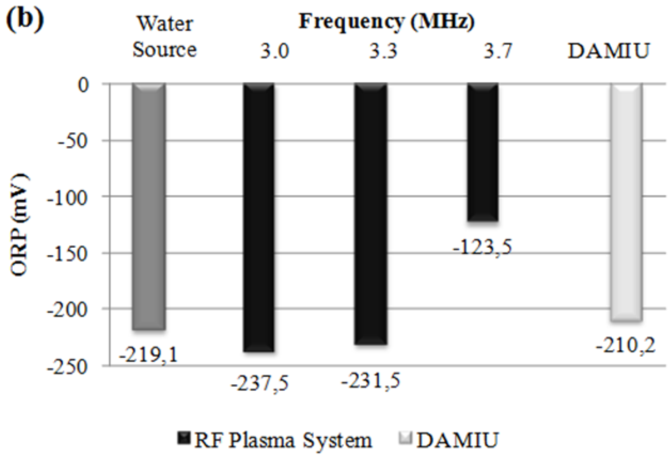


Figure 3. Frequency Effect on pH (a) and ORP (b)

4. Discussion

Increasing the applied voltage also increases the production of active species, such as •OH, H•, O_3 and H_2O_2. This is consistent with the theory that a higher frequency will increase the efficiency of microorganisms removal (fecal coliforms and total coliforms).These active species kill microorganisms by means of electroporation, which perforates the cell membrane due to the influence of an electric charge by ions and electrons, resulting in deactivation of the microorganisms. In addition, the generated active species degrade DNA so that fecal coliforms and total coliforms become inactive (Heesch et al., 2000). A comparison of removal efficiency from the present study with that of other studies is displayed in Table 2. One disadvantage of the DBD and PHV plasma system is that the electrodes are in direct contact with the water, which causes scale build-up on the surface of the electrodes.

To better understand the removal of microorganisms from water, the death rate of total coliforms and fecal coliforms was calculated using Equation 2. The results are shown in Table 3. The highest death rate of microorganisms was at 3.7 MHz with a k_D value of 3.00 h^{-1} for fecal coliforms, i.e. 9% faster than that of total coliforms (2.73 h^{-1}). This means that the removal of total coliforms is the key to remove microorganisms from water.

Table 2. Comparison of removal efficiency with other studies

Authors	Removal Efficiency	Processing time (minutes)	Plasma System
Aragi et al., 2009	Fecal Coliforms: 100%	60	Dielectric Barrier Discharge (DBD)
Hazmi et al., 2013	Fecal Coliforms: 25-100% Total Coliforms: 40-100%	60	Pulsed High Voltage (PHV) at 5-10 kV
Desmiarti et al., 2013	Fecal Coliforms: 88-95% Total Coliforms: 95-98%	60	Dielectric Barrier Discharge (DBD)at 10-13 kV
This study	Fecal Coliforms: 84-95% Total Coliforms: 83-93%	60	Radio Frequency at 3-3.7 MHz

Table 3. Microorganisms Death Constant (k_D)

Frequency (MHz)	k_D (h^{-1})	
	Fecal Coliforms	Total Coliforms
3.0	1.82	1.75
3.3	2.08	2.44
3.7	3.00	2.73

A comparison ofthe qualities of water produced by the RF plasma system and water produced through common ultraviolet systems from drinking water refill stations in Indonesia (DAMIU) can be seen in Table 4. From the water quality of the produced water it can be seen that water generated by the RF plasma system, although no pretreatment process was applied, nearly had the same quality as water produced with an ultraviolet treatment system that did use a pretreatment process. These results indicate that the RF plasma system is capable of producing potable water.

The ability of the RF plasma system to eliminate microorganisms in water makes this plasma technology a viable alternative for drinking water treatment in the future to produce potable water with aquality in accordance with health standards.

Table 4. Comparison of RF Plasma System with UV System in DAMIU

Water Quality Parameter	Unit	Sample	Sistem Plasma RF (Frequency of 3.7 MHz)	Sistem UV (from DAMIU)
pH		7.27	7.39	7.21
Turbidity	NTU	67.6	65.1	66
TDS	mg/L	404	488	378
ORP	mV	-219.1	-123.5	-210.2
Temperature	°C	30.1	30.1	28.2
Fecal Coliforms	MPN/100mL	8000	400	252
Total Coliforms	MPN/100mL	23000	1500	1100
Source of Water		River		Mountain

5. Conclusions

Based on the research conducted, the following conclusions can be drawn.

The radio-frequency plasma system generated active species that wereable to eliminate microorganisms in water (fecal coliforms and total coliforms).

In the optimum case, which was at afrequency of 3.7 MHz, the removal efficiency of fecal coliforms and total coliforms was 95.0% and 93.48% with the microorganisms death constantat 3.00 and 2.73 h^{-1}, respectively.

Increasing the frequency increased the oxidation and reduction potential (ORP) of the water.

Acknowledgments

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