



The Ultraviolet Light (UV) Technology As A Disinfection Of Drinking Water (A Literature Study)

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ABSTRACT

The used of pesticides in the village Disinfection using ultraviolet (UV) light for drinking water can eliminate pathogenic bacteria in water. The use of UV light in disinfecting water has existed from 1906 until now. UV treatment is very efficient and effective in killing microorganisms in water based on the results of previous studies. In the academic field, there have been many studies related to the use of UV light as a disinfectant for drinking water. The study used different methods and applications of research. So we need a literature review to provide a review related to

the use of ultraviolet light technology as a disinfection in drinking water. Literature study through a systematic approach to analyzing data in a simple manner that aims to collect and summarize research data that has been done before. The journals used in this study were obtained through journals that have been registered with ISSN, Science Direct, JSTOR, Scopus, Google Scholar, Nature, and DOAJ, which have been published for the past 10 years regarding the use of UV rays in disinfecting drinking water. The use of ultraviolet (UV) light can disinfect drinking water. However, 31% of the literature study results, disinfection of drinking water with UV is still above the threshold. Effective wavelengths to deactivate microorganisms in the range of 250 to 270 nm. UV rays can damage the DNA/RNA of microorganisms in water. The time of disinfection using UV depends on the method of applying the UV lamp used. The effectiveness of UV can be influenced by turbidity and total suspended solids (TSS) in water. Disinfection with UV light for drinking water must quality for the quality standards that are odorless, tasteless, colorless, TDS 500 mg/l, and have a turbidity level of 5 NTU by following per under the Minister of Health Regulation regarding drinking water requirements.

Keywords : ultraviolet (UV) light; drinking water

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I. Introduction

Drinking water is water that goes through a treatment process or without a treatment process that quality for health requirements and can be drunk directly by following per under the Regulation of the Minister of Health RI No. 492/MenKes/per/IV/2010.[1] Drinking water is a primary and important for humans health must quality for physical, chemical, and microbiological requirements. Requirements for healthy drinking water are water that does not contain *Escherichia coli* (*E. Coli*) and *Salmonella*, disease-causing microbes (pathogens), may not contain chemicals such as (the chemical elements of argon, fluorine, crom, etc), and drinking water must not smell and taste. [2]

Microorganisms found in water come from various sources such as air, soil, garbage, mud, living or dead plants, animals, other organic materials, and so on. These microorganisms can last a long time living in water, or not long lasting in water because of their unsuitable living environment. Water can be a carrier medium for pathogenic microorganisms that are harmful to health. Pathogens that are often found in water are mainly bacteria that cause digestive tract infections such as *Vibrio cholera* that causes cholera, *Shigella dysenteriae* causes dysentery, *Salmonella typhosa* causes typhus and *S. Paratyphi* causes paratífus, poliovirus, and hepatitis, and *Entamoeba histolytica* causes dysentery dysentery, *Salmonella typhosa* causes typhus and *S. paratyphi* causes paratífus, polio virus and hepatitis, and *Entamoeba histolytica* causes dysentery amoeba. To prevent the spread of the disease, treatment should be treated before consuming it.[3]

The availability of drinking water in urban areas must quality for the drinking water quality standard requirements, easily obtained. The source of clean water in Indonesia, especially in urban areas, is managed by the state, the Drinking Water Company (PAM). Basically, the water produced by PAM has fulfilled the requirements of clean water, but at the time of distribution using the piping method, there was still a leak in the pipe which caused the water to become polluted. To get proper consumption water, first treatment is needed. Drinking water treatment techniques, one of which is by boiling water is a way to obtain drinking water that is free of germs, fungi, protozoa, spores, viruses and bacteria. [4] [5]

Clean water service from PAM which has been heavily polluted and has limited services has resulted in the community using groundwater such as dug well water and drilled wells as their daily needs for clean water and drinking water. Dug well water and bore well water may not quality for the quality requirements for drinking water if not treated properly.

Disinfection is an effort to eliminate pathogenic bacteria found in water. In general, the disinfection process can be done physically and chemically. Alternatives to the chemical disinfection process usually use chlorine, ozone, and halogen compounds. While the physical disinfection process one of them is by using ultraviolet light. [6]



Ultraviolet light (UV) is part of the electromagnetic spectrum with wavelengths between 100nm - 400 nm. [7] Ultraviolet light can reduce or deactivate bacteria, viruses, and protozoa without affecting the chemical composition of water. [8]

Previous research on *E. coli* bacteria in dug well water in North Minahasa Regency showed that in the 12 dug wells studied and examined at the Laboratory of Environmental Health Engineering Laboratory it was known that the amount of *E. coli* content was in the range of 23 to > 1600 MPN per 100 ml of a water sample. [9] This does not comply with Permenkes No. 32 of 2017 concerning clean water standard that states the amount of *E. coli* as much as 0 CFU/100 ml and *Coliform* 50 CFU/100 ml. [10]

The effect of the intensity of ultraviolet light on the reduction in the number of *E. coli* bacteria shows the effect of the height of the 10 cm UV lamp on the reduction of the amount of *E. coli* according to the concept of ultraviolet disinfection. The results showed an association between the reduction of the amount of *E. coli* to the intensity of UV light, the length of time of exposure, the depth of the sample containing *E. coli* and the effect of stirring. The optimum reduction in the amount of *E. coli* bacteria reached 85% occurred at a 10 cm UV lamp height, 5 minutes exposure time at a depth of 6 mm sample accompanied by a stirring process. Whereas in the process without stirring achieving a reduction of *E. coli* 65% occurred at a height of 10 cm UV lamp, exposure time 5 minutes at a depth of 6 mm sample.[6]

The use of UV light to disinfect water on a large scale was first carried out in Marseille France from 1906 to 1909, with a volume of water of 200 m³ / day. This application was followed by UV groundwater disinfection for the city of Reuen, France. In Europe currently more than 3000 drinking water facilities use disinfection based on UV irradiation. In Belgium, the full scale application was first installed and managed in Spontin for villages in 1957 and 1958. This study states that efficient UV light in drinking water disinfection is at a wavelength of 254 nm.[11]

The use of UV light in disinfecting water has existed from 1906 until now. UV treatment is very efficient and effective in killing microorganisms in water, this is shown based on the results of previous studies of UV rays as disinfectants in water. In the academic field, there have been many studies related to the use of UV light as a disinfectant for drinking water. The study uses different methods and applications of research. So a literature review is needed to provide a review related to the topic by pressing on a single question that has been systematically identified, assessed, selected, and concluded according to predetermined criteria related to Drinking Water Disinfection Using Ultraviolet (UV). The purpose of this study is to find out the effective UV wavelengths in water disinfection and the effectiveness of UV in drinking water disinfection and to be summarized and conclusions from several previous studies.

II. Method

The method used in this research is a literature study through a systematic approach to analyzing simple data that aims to collect and summarize research data that has been done before. The journals used in this



study were obtained through ISSN, Science Direct, JSTOR, Scopus, Google Scholar, Nature, and DOAJ registered journals published during the last 10 years (2009 to 2010) related to the use of ultraviolet (UV) in disinfecting drinkingwater . The number of journals obtained was 59 findings by reading the titles, abstracts, and keywords of the journal. The data is then screened based on criteria that only uses research conducted on drinking water treatment using ultraviolet (UV) technology that is effective in being able to kill or deactivate microorganisms in water. So that obtained as many as 13 journals used in this study.

III. Results

Data that has been traced from published national and international journals are then collected and sorted according to predetermined criteria to obtain the following data :

TABLE 1. SELECTED JOURNAL

No	Researcher and Journal	UV Type	Wavelength	Exposure Time	Microorganisms	Research Result
1	Wurtele, et al., 2010[12]	UV LED stirred and flowed	269 nm and 282 nm	3-4 minutes	Spora <i>B.Subtilis</i>	GaN-based UV LEDs effectively deactivate <i>B. subtilis spores</i>
2	Zeng et al., 2019[13]	Mercury UV lamps Illuminated	254 nm	-	<i>Spora cereus</i> , <i>B. cereus bacteria</i> dan <i>E. coli</i>	The 254 nm mercury UV lamp is able to inactivate <i>E. coli</i>
3	Timmermann et al., 2015[14]	SteriPEN (UV lamp) dipped and stirred	254 nm	48 seconds, 90 seconds	<i>Escherichia coli</i> , <i>Staphylococcus aureus</i> , dan spora dari <i>Geobacillus stearothermophilus</i>	SteriPEN achieved an average reduction of more than 99.99% of bacteria and 99.57% of spores.
4	Wengraitis et al., 2012[15]	UV LED illuminated	272 nm	-	<i>E.coli</i>	At 272 nm radiation the <i>E. coli</i> disinfection sensitivity was obtained.
5	Hudaya, dkk 2010 [16]	Low pressure UV Streamed and illuminated	-	20 minutes	-	Hardness and iron content in water reduce the effectiveness of disinfection.
6	Dhama, dkk	UV Lamp	365 nm	100 minutes	<i>E.coli</i>	The best



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No	Researcher and Journal	UV Type	Wavelength	Exposure Time	Microorganisms	Research Result
	2015 [17]	illuminated				allowance for <i>E.coli</i> in reactors with 2.5 inch diameter variation reaches 80%
7	Chatterley et al., 2010[18]	UV LED illuminated	265 nm	-	<i>E.coli</i>	Germicidal UV LED 265 nm is effective for inactivation of <i>E. coli</i> in water.
8	Bowker et al., 2011[19]	UV LED Illuminated	275 nm dan 255 nm	-	<i>E.coli</i>	UV LED 275 nm is more efficient than 255 nm
9	Oguma et al., 2013[20]	UV LED Illuminated and streamed	265 nm dan 280 nm	-	<i>E.coli</i>	UV LED 280 nm and 256 nm are effective in various disinfection methods
10	Dedeh, 2019[21]	UV lights Streamed	-	-	Microbes	Still found bacteria
11	Navratinova, 2019[22]	UV lamp streamed	254 nm	75 seconds	<i>Coliform</i> dan <i>E.coli</i>	Still found bacteria
12	Yusnidar, 2012[23]	UV 35 watts Streamed	-	-	-	The resulting water can be used as raw water for drinking water
13	Syarifudin, 2014[24]	Portable UV light	-	20 minutes	<i>E.coli</i>	Able to reduce <i>E. Coli</i> 98.3% by contact time

a. UV Lamp Types and Methods

Based on the type of lamp used by previous researchers is the type of mercury UV lamps, LED UV lamps, and portable UV lamps. As for the method of using UV light in disinfecting water is by irradiation/radiation, stirring, flowing, dipping and stirring.

b. Wavelength

Based on the wavelength of UV light used by previous researchers to disinfect water was 254 nm, 265 nm, 268 nm, 272 nm, 275 nm, 282 nm, and 365 nm. Each with a different method. The



wavelength of 254 nm is the most used wavelength that is as many as 4 studies.

c. UV Exposure Time

Based on the UV exposure time used by previous researchers to disinfect water is 75 seconds, 90 seconds, 48 seconds, 3-4 minutes, 20 minutes, and 100 minutes. Each with a different method.

d. Target microorganisms

Previous researcher's UV rays killed microorganisms in water such as *Escherichia coli*, Coliform, *Staphylococcus aureus*, *B. cereus* bacteria, *B. subtilis* spores, *B. cereus* spores and spores from *Geobacillus stearothermophilus*.

Based on literature studies from all 13 studies, 31% of researches resulted in drinking water that did not quality for the requirements, namely that microorganisms were still found in water. This is due to other factors such as the state of the environment and the quality of the raw water used.

IV. Discussion

Ultraviolet (UV) radiation can effectively deactivate various microorganisms in water and has been increasingly used for water disinfection.[25] UV radiation has many advantages over conventional chemical disinfection such as chlorination or ozonation, such as no addition of chemicals, no formation of disinfection by-products harmful and no bacterial disinfectant resistance.[26] UV disinfection has been recommended as a substitute for chemical additives for surface water treatment.[26] Currently, there are more than 7000 municipal UV disinfection plants in the world[26], and small household UV disinfection systems are also available.[27]

The Wutele study examined GaN-based LED UV light at wavelengths of 269 nm and 282 nm to treat tap water from Berlin's local water supply using the static (stirred) and flow-through (flowing) method with an exposure time of 3-4 minutes. The results of this study indicate that GaN-based UV LEDs effectively deactivate *B. subtilis* spores during static and flow tests that apply variable water quality. 269 nm LEDs reach a higher level of inactivation than 282 nm LEDs for the same method.[12]

In the second study by Zeng, examined the inactivation of *B. cereus* spores, *B. cereus* bacteria, and chlorine resistant *E. coli* in drinking water using a 254 nm mercury UV lamp by irradiation. The method used is ultraviolet (UV) irradiation and 2 (two) advanced UV-based oxidation (UV-H₂O₂ and PMS). Of these three methods, the best inactivation effect is achieved by UV/PMS followed by UV/H₂O₂ and then UV only.[13]

The third journal studied by Timmermann is drinking water treatment with ultraviolet light for travelers. This research examines a UV light device called SteriPEN, which produces a wavelength of 254 nm ultraviolet light. SteriPEN offers two different time management functions, one for processing 1 liter (90



seconds, standard settings) and the other for processing 0.5 liters of water (48 seconds). In this determination there are 3 types of test organisms namely *Escherichia coli*, *Staphylococcus aureus* (ATCC 25923), and *Geobacillus stearothermophilus spores* (ATCC 7953, spore suspension). The results of this study reveal the importance of the water stirring process during irradiation and the right container. SteriPEN can deactivate up to 99.99% *E. coli* and *S. aureus* when used correctly. The effectiveness of UV irradiation in this tool depends on the concentration of germs and species. [14]

The fourth journal examined by Wengraitis was to use a pulsed UV-C LED lamp to disinfect water containing *E. coli*. At 272 nm square wavelength radiation by irradiation results obtained *E. coli* disinfection sensitivity. The results suggest that disinfection can be caused not only by photochemical changes from UV radiation but also by damage to photophysical stress caused by interference from incoming waves.[15]

The fifth journal was examined by Hudaya who used UV radiation (UV light low-pressure type Hg amalgam) in disinfecting pathogenic microbes in groundwater for drinking water by irradiation and aeration. The purpose of this study was to study the effect of groundwater characteristics (hardness and iron content) and aeration on the effectiveness of groundwater disinfection. The results showed that the aeration system was not needed in the disinfection process. Hardness and iron content in certain concentrations can reduce the effectiveness of disinfection. Groundwater with hardness content above 300 ppm and iron > 20 ppm needs to be treated first because the content can significantly disrupt the effectiveness of the disinfection process.[16]

The sixth journal examined by Dhama used ultraviolet radiation to remove *E. coli* in well water. The method in this research is to use the photolysis process with three reactor variations. In this study using materials: well water, equipment used includes: 3 sets of tubular reactors (2.5 inches, 3 inches, and 4 inches) and 3 UV lamps with wavelength 365 nm. Microbiological analysis in this study with the MPN method. The results of this study are the best removal of *E.coli* in reactors with 2.5-inch diameter variations reaching 80% with an exposure time of 100 minutes. The closer the lamp is to the reactor's circumference and sufficient exposure time, the greater the efficiency of ultraviolet radiation in killing *E.coli*.[17]

The seventh journal was studied by Chatterley using UV germicidal LEDs (265 nm) to disinfect water. UV germicidal LEDs emitted at 265 nm are more effective for inactivating *E. coli* in water and compared to conventional low pressure UV lamps. [18]

The eighth journal, examined by Bowker, stated that 275 nm UV-LED radiation was able to inactivate *E. coli* more efficiently than 255 nm UV-LED. Irradiation is done at a distance of 4 cm using collimated beams. [19]

The ninth journal was investigated by Oguma using 265 nm and 280 nm UV LED reactors with batch (shine) and flow-through methods. The results of this study mention the efficiency of inactivation with



the highest batch method namely UV-LED 280 nm while the highest efficiency of the flow-through method with UV-LED 265 nm.[20]

The tenth journal was researched by Dedeh, researching the results of disinfection using ozone and ultraviolet light which was carried out at a refillable drinking water depotism using the UV method by flowing. The results of the TPC analysis on the disinfection process using UV light on the first day the smallest TPC value is 1 colony/100 ml but on the following day, TPC tends to increase to 18 colonies/100 ml on the fifth day. [21]

The eleventh journal by Naratinova stated that bacteria were found in drinking water in a drinking water depot that had a 254 nm UV lamp with a 75 second irradiation period. And there is a relationship between sanitation with the bacteriological quality of drinking water and there is no significant relationship between the use of UV lamps, the duration of gallon filling with the bacteriological quality of drinking water. [22]

The twelfth journal was examined by Yusnidar, disinfecting groundwater for drinking water sources by using a disinfection tube using PVC parallels with a diameter of 4 inches, 35 watt UV germicidal lamps, and glass pipes. Water treatment is carried out through the stages of aeration, filtration, absorbs, and UV disinfection. The resulting water can be used as raw water for drinking water. [23]

The thirteenth journal was examined by Syarifuddin, examining portable UV disinfection to reduce *E. coli* in drinking water. The water used is dug well water. This study states that the use of ultraviolet light can reduce the amount of *E. coli* bacteria the reduction reaches 98.3% with an optimal UV contact time for water 20 minutes. The right thickness of water in the UV disinfection process reduces the number of *E. coli* bacteria at a thickness of 10 cm. The longer the exposure is given to the low thickness of the water sample, the effectiveness of the reduction of *E. Coli* bacteria will be greater. [24]

a. Types of UV Lamps

Based on the results of the above studies, thirteen journals studied using the appropriate type of lamp, namely mercury UV lamps, UV LEDs and portable UV can disinfect water by different methods by being shined/radiation, stirred, flowed, dipped and stirred effectively kill bacteria in water. Mercury lamps contain toxic and hazardous mercury to the environment and require proper construction.[27] [28] UV-LEDs at various wavelengths can be produced using different semiconductor materials. The most commonly used materials are III-nitride, including gallium nitride (GaN), aluminum gallium nitride (AlGaN), and aluminum nitride (AlN).[29]

b. UV Wavelengths

Ultraviolet (UV) disinfection systems transfer electromagnetic energy from mercury arc lamps to the organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it damages the cell's ability to reproduce. UV radiation, produced by the release of electricity through mercury vapor, penetrates the genetic material of microorganisms and inhibits its ability to reproduce. The effectiveness of the UV disinfection system depends on the characteristics of the water, the intensity of UV radiation, the amount of time microorganisms are exposed to radiation,



and the reactor configuration. The success of disinfection in each treatment is directly related to the concentration of colloids and particulates in water. [29]

The optimal wavelength for effectively deactivating microorganisms is in the range of 250 nm to 270 nm. The intensity of the radiation emitted by the lamp disappears when the distance from the lamp increases. Low pressure lamps basically emit monochromatic light at a wavelength of 253.7 nm. The standard length of low pressure lamps is 0.75 and 1.5 meters with a diameter of 1.5-2.0 cm. The ideal lamp wall temperature is between 95 and 122°F. [29] Medium-pressure lamps have about 15 to 20 times the UV intensity of low-pressure lamps so they are able to disinfect more quickly and have greater penetration capability because of their higher intensity. These lights operate at higher temperatures with higher energy consumption. [29]

Based on the "Ultraviolet Germicidal Irradiation Handbook" type and classification of ultraviolet light that the effective wavelength for germs that cause disease is 200 nm to 320 nm (UVB and UVC) and is called UV Germicidal. [30] However the effect of germs on wavelengths can vary between species. Low-pressure mercury vapor lamps emit about 95% of their energy at a wavelength of 253.7 nm, are capable of damaging DNA, and have high germ compatibility. [31]

From these theories, the 13 journals studied using UV light at wavelength matched only one study that used wavelength 365 nm.

c. Exposure Time

Several journals examined the exposure time in disinfecting drinking water using 75 seconds, 48 seconds, 90 seconds, 3-4 minutes, 20 minutes, and 100 minutes. Each study uses different methods of using UV, type of water and volume of water to produce different water quality. However, several studies in the journals studied did not mention the time of exposure.

The lack of a standardized method for measuring the length of time UV exposure to water indicates the need for a standard protocol for the duration of UV exposure to water.

d. Target Microorganisms

Water disinfection with UV is also called the term "Germicidal" which states that the UV system can change, kill or deactivate microorganisms such as virus, bacteria, and fungi. [30] This is proven by research conducted by several previous experts discussed in this study. Ultraviolet (UV) rays can kill several microorganisms such as *Coliform*, *E. coli*, *Enterococcus faecalis*, *Staphylococcus aureus*, *B. cereus* bacteria, and *B. Subtilis* spores.

e. UV Effectiveness

Ultraviolet (UV) rays are stronger disinfectants than chlorine and chloramine, and also have a wide variety of inactivations. Low dose UV is ineffective for some spores and cysts. Some microorganisms



can repair and reverse the destructive effects of UV through repairs known as "photoreactivation", or without the presence of light known as "dark repair", turbidity and total suspended solids can be used to prevent ineffective UV infections. [13]

Inactivation by UV is based on damage caused by nucleic acid (DNA/RNA) cells or viruses. This can cause the formation of pyrimidine dimers in nucleic acids and nucleic acid lesions that inhibit and prevent cells or viruses to replicate. UV absorbance from DNA peaked around 260 nm at lower wavelengths and higher absorbance was reduced and below 230 nm absorption increased again. [32]

So that it can be concluded that the effectiveness of UV is greatly influenced by wavelength, exposure time, water turbidity, and methods of using UV in drinking water treatment. This is consistent with research that has been done by previous researchers.

f. Strengths and Weaknesses of UV Water Treatment

Based on the theory that has been done previously to disinfect water states that water treatment with UV light has advantages and disadvantages, as follows: [29]

1. UV excess
 - a) UV is effective in preventing most viruses, spores, and cysts
 - b) UV disinfection is a physical process of chemical disinfectants, which eliminates the need to produce, eliminate, transport, or store hazardous or dangerous chemicals.
 - c) There are no residues that are harmful to humans or aquatic life
 - d) UV disinfection is easy to use for UV disinfection operators
 - e) UV disinfection has a shorter contact time compared to other disinfectants (about 20 to 30 seconds with low-pressure lamps).
 - f) UV disinfection equipment requires less space than other methods.
2. Lack of UV
 - a) Low doses may not be effective against some viruses, spores, and cysts
 - b) Organisms sometimes repair and reverse the destructive effects of UV through "repair," known as photoreactivation, or in the absence of light known as "dark repair".
 - c) Preventative maintenance programs are needed to control tube fouling
 - d) Turbidity and total suspended solids (TSS) in wastewater can make UV disinfection ineffective. Low-pressure UV disinfection does not look effective with TSS levels above 30 mg/L.
 - e) The cost of UV disinfection is higher compared to chlorination.

V. Conclusion

Based on the results of this study, the following conclusions can be drawn:



- a. Disinfection with UV rays for drinking water must quality for clean water quality standards that are odorless, tasteless, colorless, TDS 500 mg / l and have a turbidity level of 5 NTU in accordance with the Ministry of Health Regulation on drinking water requirements.
- b. Types of UV lamps in the use of ultraviolet rays as disinfection of drinking water using UV mercury lamps and UV-LED lamps which have advantages and disadvantages of each as well as the application in different disinfection methods.
- c. The optimal wavelength for effectively deactivating microorganisms is in the range of 250 to 270 nm. Low-pressure mercury UV lamps emit about 95% of their energy at a wavelength of 253.7 nm capable of damaging DNA and having high germ compatibility.
- d. The time of disinfection using UV depends on the method of applying the UV lamp used.
- e. The effectiveness of UV can be influenced by turbidity and total suspended solids (TSS) in water.
- f. UV disinfection in groundwater with hardness content above 300 ppm and iron > 20 ppm needs to be treated first because the content can interfere with the effectiveness of the disinfection process.



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