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Article

State of The Art: Ozone Plasma Technology for Water Purification

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Abstract. The need of clean water will continue to increase along with the increase of population. However, not all regions in Indonesia have potential for raw water sources that meet standards of clean/drinking water, so an alternative water treatment needs to be developed. Peat water treatment using ozone plasma technology is one of technological breakthroughs that can treat peat water into clean water effectively and economically. Based on the results of treating peat water using ozone plasma technology, it is proven that the technology able to treat peat water very effectively compared to the conventional refining technology. Peat water used for this study is taken from Sintang, West Kalimantan. Tested Parameters of water quality will be compared with the Regulation of Minister of Health No. 416 Year of 1990. Four parameters in raw water are carried out to be tested after treating with variations in length of contact time of 10, 12, and 15 minutes. Water quality parameters to be tested are turbidity, color, coliform, and permanganate with final quality of treating for each parameter are 5,8 NTU, 1,1 Pt-Co, below 2 MPN/100 mL, and 11,8 mg/L. There is significant decrease in a value of four parameters, which three parameters meeting the maximum limit. Permanganate as parameter that exceed the maximum limit have high probability of meeting this limit if the contact time is extended. However, ozone plasma technology also has general considerations, regarding the performance of plasma-based water purification which is the plasma-liquid interface. This paper gives an overview of the state-of-the-art in ozone plasma technology for water purification, which the technology used is plasma-based.

Keywords: Ozone plasma, water treatment, peat water.

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1. Introduction

Peat water in Indonesia is one of relatively abundant water resources. Results of the study of Geological Resource Center of Ministry of Energy and Mineral Resources report that until 2006 peat land resources in Indonesia covered a total of 26 million ha spread across Kalimantan (50%) and Sumatera (40%), while the rest were spread across Papua and other islands. The scarcity of clean water sources caused peat water has been used as an alternative.

Peat water has great potential to be treated into clean water, even with the advanced technology can be treated into drinking water. Peat water contains dissolved organic compounds that cause water to become brown and acidic, so it needs special treating before it can be consumed. Humic acid, as the main component in peat water, is humic substance as Natural Organic Matter (NOM). NOM can cause the color, increase coagulant dose, disinfectant dose, and cause harmful disinfection by product in chemical disinfection process [1]. Advanced technology is needed so that the purpose to utilize the peat water is optimal. Clean water treatment using disinfectants, filtering with membranes, ultraviolet, and activated carbon does not guarantee that the water produced has a quality that is in accordance with the quality standards. This is proven by the results of some researches that microorganisms still exist in drinking water, especially in water produced in refill drinking water depots [2].

The water in peat swamp is almost black or brownish red in color. The main reason is the presence of an organic material from peat decomposition. The black or brownish water produced from contact of water with organic litter and debris such as leaves and wood in various and at different stages of decomposition. Humic acid and tannin is derived from the decomposition of lignin and it is a principal of coloring matter. All of this played very important role in maintaining water balance in the ecosystem of peat swamp forest ecosystem [3].

Plasma is the fourth state of matter, beside gas, liquid and solid material [4]. Plasma is defined as an ionized gas. A gas will turn into plasma if the temperature is raised, causing the atoms to release some oral of their electrons. During this process, the remaining atom is positively charged, while the negative electrons move freely. Plasma technology has now begun to be used for water purification. Plasma can be generated in gas and water, forming some radicals, ions, ozone, or namely active species, which have high potential oxidation rates, break down organic compounds and kill microorganisms by decomposing pollutants without leaving secondary pollutants [4].

There are several plasma technologies that are commonly used for water purification, such as ozone (O_3), electron beam, and electrical discharge. Due to the high oxidative potential of ozone, ozone can oxidize and mineralized organic and inorganic materials. In water, ozone decomposes into oxygen, so it makes it easy to eliminate persistent substances and microbes during water treatment. Currently, ozone is widely used for processing drinking water and raw water [5]. Water treatment technology is actively being developed by oxidizing and decomposing organic pollutants in water quickly, effectively, and efficiently by using ozone.

Ozone experiences condensation at room temperature and instability at normal air pressure, colorless to bluish and dia-magnetic gas, condensing to a deep-blue liquid at –110.5 °C and solidifying to a black-violet crystal at –192.5 °C (80 K). In high concentrations, ozone in the gaseous form will smell sour like chlorine, if in a small concentration it does not smell. Ozone formation occurs endothermically with the formation of enthalpy 144.8 kJ/mol so that the molecule is unstable and decomposes in solution into oxygen through radical chain reactions. With its high electrochemical potential, ozone can oxidize all metals to the highest oxidation state [5].

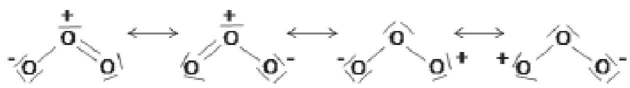

Fig. 1. Ozone molecular mesomeric structure.

Our groundwater, streams, lakes, rivers, and oceans are subject to a wide range of human caused assaults, which some of these problems are associated with large molecular structures and unoxidized molecules. Ozone breaks down large and long chain molecules into smaller building blocks. These smaller molecules are then usually more biodegradable and less dangerous [6]. Ozone at elevated pH will be decomposed into hydroxyl radicals [7].

Generally, there are types of procedures for ozone formation: thermal ozone production, photochemical production with UV light, radiochemical production, chemical ozone production, electrical gas discharge, and electrolytic ozone production [5]. For specific, ozone can be produced in two ways: Electrical Discharge, Plasma Corona Discharge which is known as Ozone Plasma. Electrical Discharge is the formation of O_3 oxidizers through the O_2 ionization process using alternating electric current high voltage in the air [8]. Whereas, Plasma Corona Discharge is the formation of O_3 through the O_2 ionization process by using relatively high voltage electricity using low currents that are emitted transversely between plasma cells so that the production costs are relatively lower or cheaper to be applied in water treatment.

In municipal wastewater treatment, ozone has been studied primarily for disinfecting (following primary or secondary treatment), but also for lowering the of biological (BOD) and chemical oxygen demand (COD), oxidation of ammonia, and removal of color, nutrients and suspended solids [9]. Ozone plasma in water can produce various kinds of active ion species that have the potential to decompose the content of organic compounds in water. In addition, plasma can also produce UV light and shock waves that have the potential to significantly decompose organic compounds in water [2].

Drinking water treatment with an ozone plasma system can replace the use of chlorine and activated carbon which has the function of killing microorganisms, and at the same time can decompose the content of organic compounds. One development and application of ozone plasma technology for water treatment is to use ozone (O_3). Commercially, large quantities of ozone are produced in especially engineered corona discharges. The corona discharge method involves the passage of a dry oxygen- bearing gas through a corona discharge. Common feed gas streams are oxygen, air and recycle streams containing oxygen, nitrogen, argon, carbon dioxide and perhaps other diluents [9].

In purifying water, ozone and hydroxide radicals formed in the ozone plasma system function as cleaning agents, strong oxidizers, disinfection sterilizers, deodorizers, self-purification, and even color decomposers. By looking at the ozone plasma working system and the characteristics of ozone, this study conducted an in-depth analysis to find out the benefits of using ozone plasma to treat peat water into clean/drinking water, especially in peat areas. This regarding that the use of ozone plasma technology has not been implemented in the treatment of peat water, whereas in Indonesia there are many areas experiences clean water crisis, especially in areas that have raw water in the form of peat water. This paper gives an overview of the state-of-the-art in ozone plasma technology for water purification, which the technology used is plasma-based.

2. Methodology

2.1. Research Method

This study uses independent variables and dependent variables. The independent variables are peat water sample originating from Sintang, West Kalimantan, and the length of time of contact (t_c) between water in ozone plasma unit. The dependent variables are the value of coliform, turbidity, color, and permanganate. The equipment used in this study is water purification unit with ozone plasma technology. This technology has been widely marketed and is commonly applied for treating clean water. With a series of experiments in the various of t_c, it will be known the effectiveness of the technology in treating the raw water (peat water) into drinking water.

The experiment was performed using natural peat water. The characteristics of peat water sample are concluded in Table 1. Some contaminants exceed the maximum limit regarding The Regulation of Minister of Health No. 416 Year of 1990, which are organics, turbidity, and coliform.

Table 1. Characteristics of peat water sample.

Parameters	Unit	Test Results	The Regulation of Minister of Health No. 416 Year of 1990
Organic	mg/L	122,3	10
Iron	mg/L	0,62	1,0
Dissolved Solid	mg/L	138	1.500
Color	TCU	7,8	50
Turbidity	NTU	50,15	25
pH		6,80	6,5 – 9,0
Coliform	MPN/100 mL	13	10

2.2. Contact Mechanism and Ozone Plasma Reaction

The contact mechanism of ozone plasma in treating raw water (peat water) is based on the chemical-physical operation process, which leads to the formation of OH^- when the plasma unit is in contact with water (H_2O). The overview of this contact mechanism can be seen in Fig. 2. Plasma units with a relatively high supply of electricity in water will produce ion particle charged with ultrasound energy that are resistant to UV and even shock waves, thus encouraging the formation of OH^- ions in solution [10]. In addition, the chemistry of plasma driven in the gas phase produces reactive oxygen and hydrogen peroxide, which are not only radical, but also ozone, which needed to break down covalent gas so that it can produce plasma electrons. During the radical gas phase, there will be a diffusion process and changes in Henry's constant. Plasma also interacts with water, which directly produces reactive ion species at the interface layer.

Interaction between ozone plasma and liquid will be able to provide an addition of oxidizers which will affect the oxidation level which is relatively much better than conventional methods, including: (1) consumables are not needed, because ozone plasma can be produced from ordinary air or the liquid itself, (2) the level of decomposition of organic compounds is relatively more effective, (3) because consumables are not needed, the costs and infrastructure normally used for consumables can be removed or substituted for the costs of overcoming other obstacles that may be encountered in water treatment, (4) ozone plasma application is inherently modular and can also be used as a final stage in water treatment system that is no different from conventional UV stages for disinfection systems. The use of ozone plasma also allows for the

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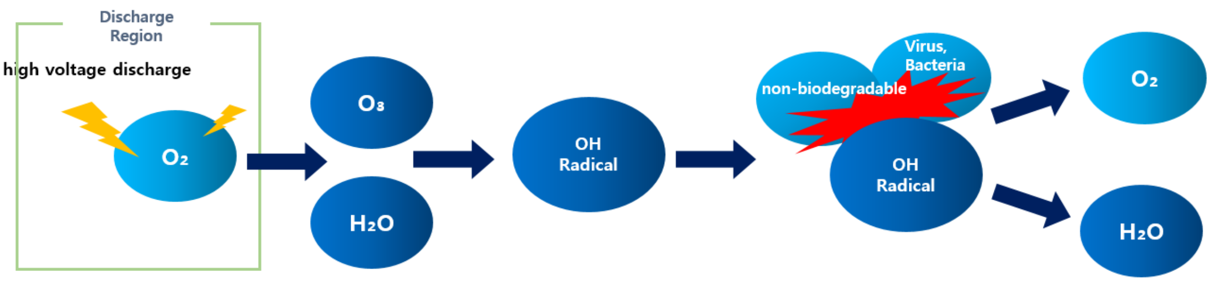

Fig. 2. Overview of ozone generation mechanism by plasma ozone system.

Fig. 3. Non-contact plasma discharge tube.

In this ozone plasma system, peat water will be exposed directly with the concentration of O_3 produced through a plasma non-contact tube, which the tube is shown in Fig. 3. By using this system, peat water is treated effectively and efficiently to produce clean water that is suitable for consumption. The mechanism for purifying water with an ozone plasma system begins by injecting oxygen into an area that has a high voltage. O_3 will be produced when passing through the corona plasma unit. When O_3 in the water content passes through a charged tube, radical hydroxide, an oxidizing compound, such as hydrogen peroxide is also produced in the presence of internal high stresses. With the mechanism, there will be more production of effective hydroxide radicals. The oxidation ability possessed by O_3 and hydroxide radicals (OH^-) will be able to destroy germs and decompose materials that cannot be degraded by conventional means. The ozone and hydroxide radicals that have been used will then break down into H_2O and O_2 forms which will then be released as treated water which has high dissolved oxygen and clarity that meet clean water standard.

In this study, an experimental treatment of peat water is conducted by varying the t_c, which is 10 minutes, 12 minutes, and 15 minutes. Time variations are made to determine the estimated effective time required by ozone plasma technology to reduce the parameters of coliform, turbidity, color, and permanganate, which are the dominant parameters in peat water in general.

In wastewater treatment, ozonation provides better organic material degradation capabilities. If ozone is used in the process of disinfection of treated water, no by-products are produced. This depends on the constituent matrix of water, namely alkalinity, pH, and temperature. The use of ozone is also able to minimize the use of chemicals. Overall, the concentration of ozone in the air should be reduced to 0.1 ppm. Ozone concentrations of 2-5 mg/L are needed to remove organic material in water before processing. The amount of ozone can be determined by using several methods, including by using iodometric titration or N, N-diethyl-p-phenylenediamine (DPD) oxidation with iodine so that it can be analysed by spectrophotometer. In addition, it can also use the indigo method in which colour removal with ozone is detected using a photometer [5].

3. Results

In this study, tests are carried out on four water quality parameters, which are coliform, turbidity, color, and permanganate. Coliforms in water need to be checked because even though they are not dangerous to humans, coliforms are a good indicator of the presence of pathogenic microorganisms in water. Pathogenic microorganism is a variety of bacteria, parasites, and viruses that have the potential to endanger human health [11]. The presence of coliforms in water samples will be greatly considered because it can indicate the effectiveness of the disinfection process. Chlorine as a disinfectant in the treating of peat water cannot be used because in the chlorine disinfecting process, *trihalomethane* (THM) dangerous compounds will be formed which can be carcinogenic which are triggered by the higher solubility of metals in water because the pH of water is lower [12]. For peat swampy water, it is normal that pH and DO are generally low [3].

Table 2. Characteristics of peat water sample at times 10 minutes.

Parameters	**Unit**	**Test Results**	**The Regulation of Minister of Health No. 416 Year of 1990**
Organic	mg/L	26,3	10
Iron	mg/L	1,5	1,0
Dissolved Solid	mg/L	186	1.500
Color	TCU	3,5	50
Turbidity	NTU	34,6	25
pH		6,40	6,5 – 9,0
Coliform	MPN/100 mL	<2	10

Table 3. Characteristics of peat water sample at times 12 minutes.

Parameters	**Unit**	**Test Results**	**The Regulation of Minister of Health No. 416 Year of 1990**
Organic	mg/L	22,8	10
Iron	mg/L	1,0	1,0
Dissolved Solid	mg/L	214	1.500
Color	TCU	2,7	50
Turbidity	NTU	12,6	25
pH		6,74	6,5 – 9,0
Coliform	MPN/100 mL	<2	10

Table 4. Characteristics of peat water sample at times 15 minutes.

Parameters	**Unit**	**Test Results**	**The Regulation of Minister of Health No. 416 Year of 1990**
Organic	mg/L	11,8	10
Iron	mg/L	0,33	1,0
Dissolved Solid	mg/L	288	1.500
Color	TCU	1,1	50
Turbidity	NTU	5,84	25
pH		7,38	6,5 – 9,0
Coliform	MPN/100 mL	<2	10

The treated water from ozone plasma treatment will be compared with the quality standard stated in the Regulation of Minister of Health No. 416 Year of 1990 about Water Quality Requirements and Supervision for Clean Water. In testing the parameter of coliform, the raw water has a value of 13 MPN/100 mL, where the allowable limit is 10 MPN/100 mL. After 10 minutes of treating with ozone plasma technology, the coliform level is below 2 MPN/100 mL (see Table 2). By looking at the effectiveness of the ozone plasma technology on water purification, the disinfection process in the ozone plasma worked very well.

Turbidity in water can be defined as a decrease in the transparency of a solution because of the presence of suspended or dissolved materials that can cause light to be dispersed, reflected and not transmitted straight. The higher the level of turbidity of water, the lighter will be dispersed [13]. Turbidity in water is also caused by colloidal particles, and suspended particles, such as clay, silt soils, fine grains which are divided into organic and inorganic materials, plankton and microscopic organisms. Iron bacteria can also be a source of turbidity. The turbidity also acts as an important indicator for organic pollution, the run-off of suspended material and heavy rain fall in the area [14].

Turbidity removal can be done by giving a coagulant, which is then processed through coagulation and flocculation. In this study, the process is not carried out by given the magnitude of the ability of hydroxide radicals to decompose non-degraded material. This can be seen from the results of experiments that showed a decrease in turbidity level from the previous 50,15 NTU in raw water to 34,6 NTU in water treated with t_c 10 minutes (see Table 2), 12,6 NTU with t_c 12 minutes (see Table 3), and 5,84 NTU with t_c 15 minutes (see Table 4). When compared with the quality standard (25 NTU), purification of water with ozone plasma technology can meet quality standards while being able to cut the use of chemicals as a coagulant which commonly used in the water treatment process.

Natural colors in water occur because of the presence of complex organic molecules that are contained from humus substances such as leaves. The color in the water can also increase concentrated if there is the presence of suspended substances. Color on water usually affects aesthetics compared to health problems [11]. The water in peat swamp is almost black in color. The main reason is the presence of an organic material from peat decomposition [15]. Peat water has a very high color intensity, namely brownish red color, which is caused by a high content of organic matter dissolved mainly in the form of humus acid and its derivatives. Humus acid, derived from the decomposition of organic matter, such as leaves, trees, or wood with various levels of decomposition. In some cases, the color will be higher due to the presence of iron metal which is bound by organic acids dissolved in the water.

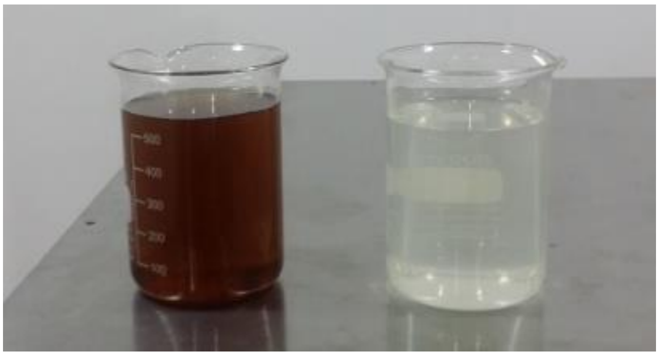

Fig. 4. Peat water condition before and after plasma ozone treatment.

Color analysis is performed to determine the color of the treated water. Watercolor is used as a parameter to indicate the physical and chemical constituents in water [7]. In this research, the color of water is only visually observed as shown in Fig. 4, it can be seen that with the very strong oxidation ability of O_3 and OH^- hydroxide radicals, the raw water (Peat Water) that was originally brownish red and smelled turned to be clear, odorless and free of microorganisms. Non-contact plasma discharge that takes place simultaneously prevents the abrasion of the electrodes between the insulators so that the tool will last longer because it can prevent extreme increases in temperature as happened with water treatment technology with conventional Ozone. This technology is also equipped with an O_3 solvent. After the reaction ends, there is no residual left and the result is in the form of water with high O_2 levels.

Technique of color removal can be done in various ways, including: Coagulation-flocculation-sedimentation-filtration, oxidation-reduction, activated carbon, or adsorption-absorption. The technique of color removal basically requires additional media or chemicals that will have a significant effect on the cost of water treatment. In this research, no additional media or chemicals are used at all, only by maximizing the processes that occur in ozone plasma system, where O_3 and OH^- dissolved in water will function to remove color. The color content of the raw water of peat water shows value of 7,8 Pt-Co with maximum limit according to the Regulation of Minister of Health No. 416 Year of 1990 is 50 Pt-Co. With t_c 10 minute, treating the water with ozone plasma unit achieves 3,5 Pt-Co (see Table 2) and if t_c is increased to 15 minutes, the color level of treated water reaches 1,1 Pt-Co (see Table 4). This shows that treating peat water using ozone plasma has been proven to reduce the color level in the water.

Permanganate number is used to measure the high content of organic matter in water. Permanganate value is the amount of milligram of potassium permanganate needed to oxidize organic matter in 1000 mL of water in boiling conditions [16]. Excessive organic matter in drinking water is not permitted because in addition to causing unwanted colors, smells and tastes, it may also be toxic both directly and after compounding with other existing substances [17]. Permanganate number is closely related to the value of COD (Chemical Oxygen Demand), BOD (Biochemical Oxygen Demand), and DO (Dissolved Oxygen). The relationship between BOD and COD values with permanganate numbers are the three parameters which together indicate the number of organic (and non-organic) compounds dissolved in the waters. Thus, the higher the permanganate number, the higher the COD value and the BOD value.

The tubular plasma reactor is designed to maximize the time in which a fluid element moving axially through the reactor is in contact with the plasma [18]. The more complex water treatment system is needed if the BOD and COD content is high. The permanganate number in the peat water is 122,3 mg/L with allowable limit is 10 mg/L. In this study, it is found that after 10 minutes of treating, the permanganate number can be reduced to 26,3 mg/L (see Table 2). By using t_c 12 minutes, the permanganate number can be reduced to 22,8 mg/L (see Table 3). By extending t_c 3 minutes which is for total of 15 minutes of treating, the final value of permanganate number drops by almost half, reaching 11,8 mg/L (see Table 4).

By looking at the results of this experiment, the treating experiments with t_c 15 minutes can significantly reduce the level of permanganate in peat water close to the quality standard. It can be said that the permanganate method in acidic condition has a better recovery [19]. This is probably since most of the organic matters were oxidized more completely in acidic than in alkaline conditions [20]. To obtain better permanganate numbers, treating by the ozone plasma technology is needed with a t_c of more than 15 minutes or an estimated treating time of no more than 20 minutes. The results of this experimental treatment using ozone plasma technology are shown in Fig. 5.

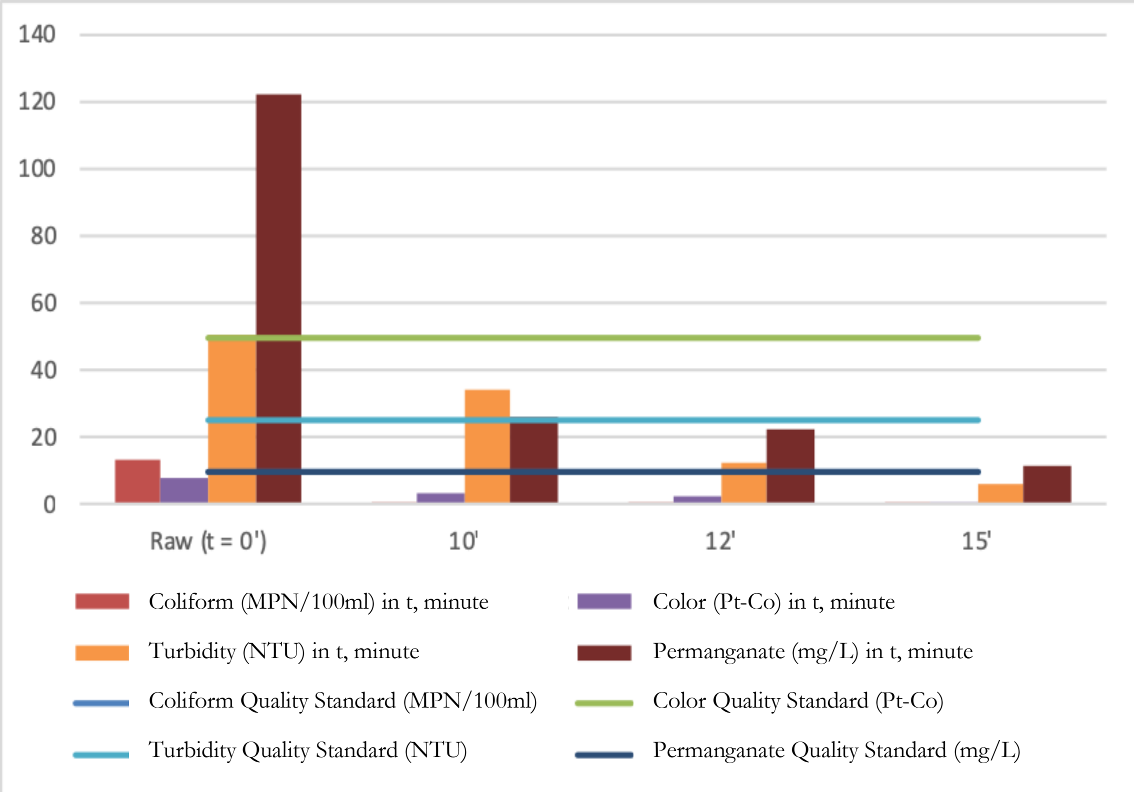

Fig. 5. Results of peat water treatment with ozone plasma technology.

4. Discussion

Peat water which is widely found on the islands of Borneo and Sumatra is a type of water that is commonly found in locations that often occur in tidal conditions, swampy areas, and lowlands. In general, peat water has acidic and brown properties and based on the Government Regulation No. 82 Year of 2001 concerning management of water quality and water pollution control, defines peat water as unsuitable for consumption so it must be treated in advance so that it is suitable for consumption [21], while swampy areas generally only have surface water from peat water.

One appropriate solution is to use water treatment plant that can treat the peat water into consumable water. But conventional technology is not appropriate to be used to treat peat water. This is because to treat peat water into consumable water requires high technology and expensive costs so that its affordability by the community will be very low. Water treatment technology using ozone plasma is proven to be able to treat peat water into consumable water. Ozone itself nowadays has various applications in some sectors, particularly for water treatment (see Fig. 6.)

The experiment is to examine the operation condition that can result in the highest removal efficiency. The determination of settling time is based on the shortest settling time which can result in the highest removal efficiency. After treating the peat water by ozone plasma technology with t_c 15 minutes, three parameters tested (coliform, color, and turbidity) are proven to be able to be treated and to meet the clean water quality standards based on the Regulation of Minister of Health No. 416 Year of 1990. However, there is one parameter that has not met the maximum limit of clean water, which is permanganate number. Even though at t_c 15 minutes the permanganate number is still above the maximum limit, there is a significant decrease and it is highly probable that permanganate number can be below the maximum limit if it is treated with a longer contact time.

Figure 7 depicts the retrofit of using ozone plasma technology in comparison with conventional technology. To remove contaminants such as color and turbidity in peat water, ozone plasma technology can replace some processes used in clean/drinking water treatment. Coagulation-flocculation-sedimentation-filtration, oxidation-reduction, activated carbon, or adsorption-absorption are some processes used to remove color and turbidity contaminant in peat water. This removal basically requires additional media or chemicals that will have a significant effect on the cost of water treatment. Meanwhile, no additional media or chemicals are used in the application of ozone plasma technology, only by maximizing the processes that occur in ozone plasma system, where O_3 and OH^- dissolved in water will remove the contaminants.

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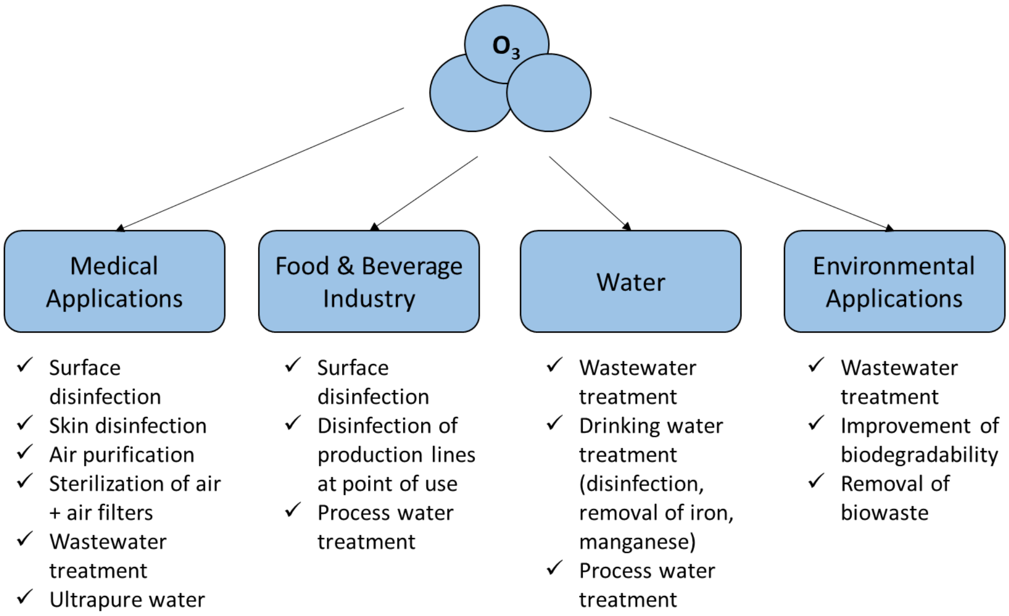

Fig. 6. Ozone applications in various sectors.

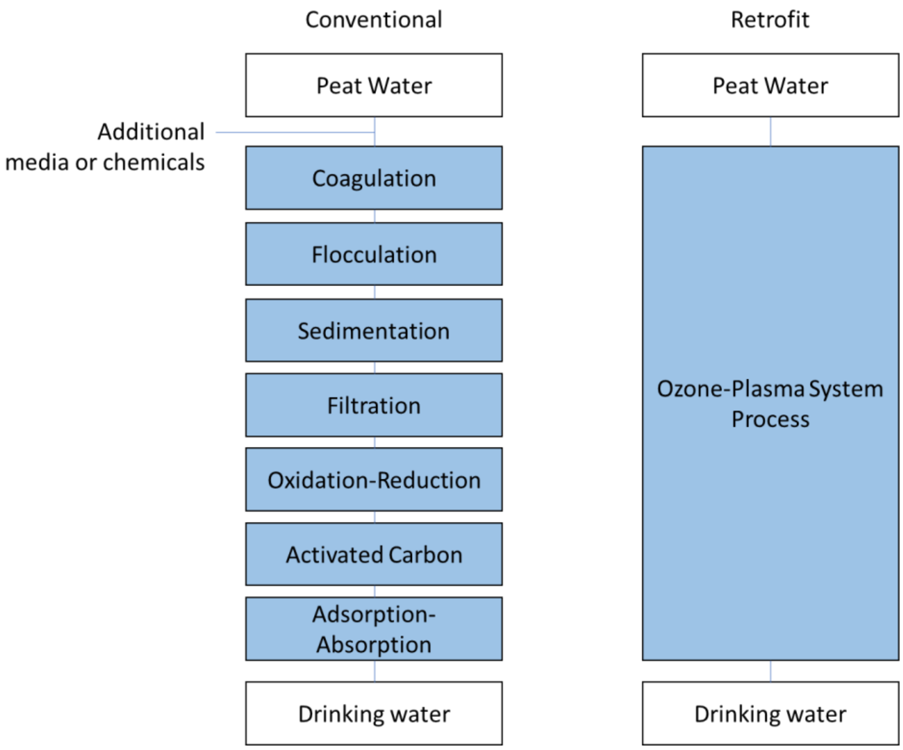

Fig. 7. Ozone applications in various sectors.

Ozone that decomposes in water through reactive radicals will turn into hydroxyl radicals, both ozone and the resulting decomposition products will be able to act with the water component. The application of ultraviolet light which is the result of the formation of ozone in a radical reactive process occurs because of the existence of further oxidation processes (advanced oxidation process (AOP)). Organic molecules with high electron densities generally react quickly with ozone. When ozone undergoes oxidation to form aldehydes or carbon acids, it can have an impact on increasing the polarity and biodegradability of organic matter [5].

Plasma in contact with liquid water drives AOPs within the water. These plasmas are typically generated nonthermally at atmospheric pressure, so no vacuum is required. Reactive oxygen and nitrogen species derived from the gas phase can diffuse into the liquid and drive secondary reactions that can produce OH radicals in the bulk liquid. Indeed, plasma treatments have demonstrated excellent degradation of surfactant-like contaminants, such as perfluorooctanoic acid, which, in general, are difficult to remove with conventional treatment methods. The only economic driver regarding plasma-based approaches is electric power cost [22].

Ozone plasma technology also has general considerations, regarding the performance of plasma-based water purification. The key driver of plasma-induced reactivity in liquid water is the plasma-liquid interface. The contact area between the plasma and the water ultimately determines the treatable throughput; thus, understanding the physics and chemistry of the plasma-liquid interface is key to optimizing plasma water reactors. Understanding the effectiveness of a reactor requires in turn an understanding of the mass transfer rates of the various reactive species produced at the interface [22].

Plasma-based water purification utilizes plasma to generate AOPs in liquid water using air or water itself as the active medium. Advanced oxidation is an effective method of treating recalcitrant contaminants and contaminants of emerging concern. To scale up the issue, it is regarding atmospheric pressure plasma technology is that the discharges tend to be filamentary in form. This is largely due to the reduced electron diffusion lengths, typically micrometers, at one atmosphere. In this regard, the application of high voltage at atmospheric pressure produces discharges that are very localized and reminiscent of lightning. This very localized nature makes it difficult to integrate into large flow rate geometries. In the lab, contaminated water volumes of order a liter have been treated, but as mentioned earlier, treatment flows of order 10 s of l/min are required in practice [22].

5. Conclusion

Based on the results of treating peat water using ozone plasma technology, it is proven that the technology able to treat peat water very effectively compared to the conventional refining technology. At the t_c 15 minutes treating peat water with ozone plasma, 3 of 4 test parameters (coliform, color, and turbidity) can be treated to be below the maximum limit. While another test parameter can be reduced significantly so the value is only slightly exceeding the maximum limit, and there is a high probability that the value can be treated to below the maximum limit by increasing the contact time of peat water in the ozone plasma unit. The use of ozone plasma to treat peat water will be able to reduce the use of chemicals to treat water into clean water so that it will have a significant impact on the cost of treating peat water. Thus, the use of this ozone plasma technology to treat peat water will be an effective cost to be developed and applied in many places on the islands of Kalimantan and Sumatra in Indonesia. This regarding that in the areas that have raw water in the form of peat water, the use of ozone plasma technology can be one of appropriate alternative to treat the raw water into clean or drinking water.

However, ozone plasma technology also has general considerations, regarding the performance of plasma-based water purification. The key driver of plasma-induced reactivity in liquid water is the plasma-liquid interface. The contact area between the plasma and the water ultimately determines the treatable throughput; thus, understanding the physics and chemistry of the plasma-liquid interface is key to optimizing plasma water reactors [22]. Plasma-based water purification utilizes plasma to generate AOPs in liquid water using air or water itself as the active medium. Advanced oxidation is an effective method of treating recalcitrant contaminants and contaminants of emerging concern. To scale up, it is regarding atmospheric pressure plasma technology which the discharges tend to be in filamentary form [22].

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Dwi Lintang Lestari, photograph and biography not available at the time of publication.

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