The Comparison between types of electrodes in Dielectric Barrier Discharge (DBD) plasma for obtaining potable water: a review

Djulil Amri¹, Zainuddin Nawawi¹ and Muhammad Irfan Jambak¹
¹Faculty of Engineering, Sriwijaya University, Indonesia
E-mail: djulilamri@ft.unsri.ac.id

Abstract. Water is a basic human need in everyday life. However in some areas consumable clean water is still unattainable. There is an urgent need for water purification equipment. Several researches on water purification devices has been carried out with different methods. One of the methods amongst them is using the Dielectric Barrier Discharge Reactors. This method applies appropriate temperatures to make it safe for use. This paper discusses about the various methods used in water purification. The previous researchers discussed a lot about the parameters of the ozone producing capability. They also explained the characteristics and effects of voltage related to voltage sources. Furthermore, the factor of non-potable water is also used as a research material. Based on these previous researches, the researcher reviewed and investigated two of the types of electrodes used - The screw and helix type. They were examined in the same reactor tube length, thickness and tube material dimensions.

1. Introduction
The water pollution is a major cause of the unclean and infected water problems in the world. Various methods have been conducted to overcome and prevent this problem. One of the main methods used is the utilization of ozone. Ozone is a gas formed from three oxygen atoms. They are highly reactive and more unstable than oxygen. Ozone is a strong oxidizer with oxidation power of six times the strength of chlorine oxidation. Furthermore, because of its characteristics, ozone is widely used to sterilize water from organic waste, color, disinfectants and viruses. It also could increase the supplements in water because the final reaction results are in the form of pure oxygen [1-4].

Ozone was first discovered by a European researcher named C.F. Schonbein in 1839. He identified odors in the anode during electrolysis of water as a new compound called ozone. Ozone was first used commercially in 1907 to produce good water [5]. Ozone is an oxidant that can be applied to water and air. Some food processing procedures also make use ozone to control the chemical reactions. The disinfectants that exist today are also based on ozone generators [6].

Ozone can be produced in three ways which include: a) By electrical discharge. b) By ultraviolet arc.[7] By electrical chemistry [8] [9]. The ozone source applied practically is generally an electrical discharge commonly called the corona discharge [8,] [9] [10].

The Ozone Reactor with the Dielectric Barrier Discharge Plasma technique is a simple and powerful method for producing ozone [11] [12].
The factors that influence the efficiency of ozone production include: gap width, voltage usage, material and electrode configuration, and discharge parameters [12] [13].

In this research, one of the factors taken as the main topic is the material and electrode configurations. The electrode configurations discussed in this study are 2 types of electrodes, which are the coil and screw type.

In this paper, one of the major functions of a Dielectric Barrier Discharge (DBD) reactor is its use for water treatment. This DBD reactor is used to ease the process of producing any substance in nature in solid or liquid form. The DBD reactor is used to fertilize agricultural land by eliminating the harmful elements in the soil. Additionally, it also helps plants to increase yields. Furthermore, it is also a tool used to reduce levels of NOX, CO2 and liquid waste levels generated by the textile industry, hospitals and others sectors. It could also be used to sterilize water to obtain consumable/potable water.

The Dielectric Barrier Discharge reactors have been investigated and its advantages explored by previous researchers based on the method and design form. Comparisons will be made based on the shape of the electrode type from the reactor, the electrode material, the reactor dimensions including the tube diameter and so on.

In organizing the analysis, this research is divided into several parts. In the Section 1 there are: the background, problems and objectives discussed. The electrode in the Dielectric Barrier Discharge reactor is discussed in Section 2. The analysis of Dielectric Barrier Discharge is explained in section 3. The last, conclusions will be drawn from.

2. The Electrodes In Dielectric Barrier Discharge (Dbd) Reactor

One of the important components used in making a DBD reactor is electrodes. There are many forms of electrodes that have been made by researchers previously, they include:

A Cylindrical Spiral type of Electrode

The design of a Dielectric Barrier Release Reactor with a cylindrical configuration would result to an increased ozone concentration in line with the increase in voltage and number of spirals. In this design, the ozone concentration will reduce as the distance between the spiral electrodes increase. Therefore, even if ionization occurs, ozone will not form. In the study of DBD which uses this cylindrical spiral type reactor configuration, a high voltage is required up to 25 kV, and the maximum frequency is 23 kHz. The measurements carried out on this type of reactor are variations in voltage applications. This reactor consists of an active electrode in a spiral copper wire with a varying wire diameter between 0.4 and 1.2mm [14].

The development of the helix coil (spiral) type is done by examining the optimal distance between each change of helix coil. It is primarily made of copper wire. It serves as an inner electrode while the cylindrical electrode serves as an outer electrode with stainless steel material. These two electrodes are separated by an air gap. The inner electrode is connected to a high voltage source and the outer electrode is connected to the ground. Based on the results of the experiments conducted, it was found that the electrodes developed can be used in ozone generators to disinfect micro bacteria in hospitals. [15].

Furthermore, another researcher who used cylindrical spiral wire configuration discussed the variation in the number of turns used in spiral electrodes, with materials made of copper wire. The spiral electrode is inserted into the pyrex type of dielectric barrier tube. On the outside, the Dielectric Barrier Discharge reactor is covered by a copper plate. This experiment was aimed at; 1) Finding the effect of voltage on the average of current. 2) Finding the effect of voltage on the concentration. 3) Effect of impedance on ozone concentration 4) Effect of power on ozone concentration [16].
b. The Screw type electrodes
The use of screw type reactors was carried out by Tomoyuki et al. This research was carried out by changing the outer side electrodes. It was aimed at examining the external effects of the electrodes formed on the generation of ozone properties. This study used two different external electrode forms. They include: a). one of the electrodes which has a width of 110mm and b). three divided-electrodes with 1cm × 3 (4cm electrode distance). The experimental results obtained from the research showed that a greater efficiency of the ozone generator will be obtained when the outer electrode value of 110mm is used. The screw type electrodes are also used by Bunpei Ueda et al. This study examines the characteristics of Dielectric Barrier Discharge reactors as ozone generators. It proved that ozone concentration depends on the outer electrode, the velocity of the flow from the gas source and the voltage used. The experiments using the screw type of electrodes were intended test the effect of the ozone generation characteristics when using an external electrode at a distance of 30mm or an outlier electrode. It is also influenced by dividing the electrode on ozone generation equipment. The results showed that ozone concentration produced was relatively efficient [19].

c. Pyramid type of electrode
In order to obtain the ozone gas, we can also use a Dielectric Barrier Discharge reactor with pyramid electrodes carried out by M. Takayama et al as shown in Figure 1. The aim of their research was to obtain the characteristics of an effective pyramid type of electrode to reduce the falling voltage and ozone concentration by changing the voltage. This pyramid type electrode has a high concentration and frequency. [20].

d. Multipoint type of electrode
The use of the Dielectric Barrier Discharges reactors is related to the way the reactor works. The research by using multipoint type of electrodes has been investigated by previous researchers which were applied to reduce or eliminate NOX gas. [22] as shown in Figure 2 below.
Other researchers used a multipoint DBD reactor comparing the shape of the electrode used for NOX treatment. The results obtained in the study proved that the measurement of discharge generation using multipoint to plane is better than micro discharge with electrode plane. By using a multi-point plane geometry electrode, low voltage electrodes can be used. [24].

From the several types of electrode methods, there are several other electrode configuration methods including; the wire-cylinder, spiral cylinders with dielectric wire cylinders, the discharge barriers with DBD, and the spiral cylinders with DBD. The tests from four ozone reactors have been carried out by treating wastewater. Based on the comparison of the four ozone reactors, the wastewater treatment characteristics will be maximized in the configuration of the ozone-electrode spiral-cylinder reactor with DBD [25].

The research conducted by Koichi Takaki et al, is still developing and makes use of 3 configurations namely; flat, slot and multi point. From the result obtained, the flow velocity will increase depending on the ozone concentration for the flat electrode. While at the multipoint electrodes, there is a very little dependence. The configuration will affect the number of micro discharge [26].

Meanwhile other researchers conducted experiments which discussed the effect of electrode geometry on the reduction of benzene values in the Dielectric Barrier Discharge. It made use of 3 electrodes, namely; helix (spiral), screw (bolt), and rod electrode. In reactors that use coil electrodes, it showed a better form in reducing the electric losses on the barrier compared to using a screw or rod [27].

3. The Analysis Of Dielectric Barrier Discharge

Ozone could be produced by using two electrodes with a high voltage and gas input. Both electrodes are protected by dielectric materials to avoid arc discharge. After this system is run, it forms ozone. The factors that can affect ozone formation in general are voltage, dielectric material, pressure, configuration system of the plasma reactor and the gas input in the plasma reactor. In this study, the mean of mobility of the plasma charge carriers is the speed obtained by an ion that moves when passing through a gas in each electric field unit. By using the modified Robinson equation [28], the average charge carrier mobility in plasma produced by a dielectric barrier discharge reactor can be calculated by the following equations:

\[ I_s = \frac{25 \mu_{RT} \varepsilon_i}{d^3} (V - V_i)^2 \]  
\[ \sqrt{I} = \frac{25 \mu_{RT} \varepsilon_i}{d^3} V \]

with the gradient value is C, then

\[ C = \frac{25 \mu_{RT} \varepsilon_i}{d^3} \]

Therefore;

\[ \mu_{RT} = \frac{C^2 d^3}{25 \varepsilon_i} \]

Where \( I_s \) is a unipolar saturation current(mA), \( \mu \) is the value of ion mobility (cm² / volt seconds), \( \varepsilon_i \) is the total permittivity for 2 dielectric materials, \( V, V_i \) is the operating voltage and corona threshold voltage (volts) [29], \( C \) is a gradient obtained from a characteristic linear graph, \( \sqrt{I} \) is against voltage (V), \( S \) is the passive electrode surface area (cm), \( r \) is the barrier finger (cm), \( l \) is the diameter of the electrode, \( n \) is the number of turns (cm) and \( d \) is the distance between electrodes (cm).

Fig. 3. It is a tool design that will be carried out by referring to the theory of the Dielectric Barrier Reactor using a direct current source. Based on the results of previous researchers, it is necessary to further examine the discussion of the Dielectric Barrier reactor by comparing two forms (types) of applications with different types of electrodes between screw type and helix type. The method applied
by the researcher determines if he will obtain the ozone gas. The comparison of these two types of electrodes can be seen in Fig. 4. This research also designs the reactor as a tool for purifying water suitable for consumption. The water to be purified will be obtained from water sources which are not yet suitable for use in areas that require water purification equipment.

Figure 3. Screw and helix electrode

Figure 4. The Comparison between Electrode Types

4. Conclusion
Based on the several studies that have been carried out by previous researchers, the writer conducted a study by reviewing the Dielectric Barrier Discharge (DBD) reactor by comparing 2 types of electrodes - the helix (spiral) and screw (bolt) type. This present research is conducted in order to find out the best type of electrode for ozone production and its ability to purify water to be suitable for use. The results of this study could be used as a reference in planning and designing a system capable of purifying water and producing ozone. In future, the project of making the DBD reactor equipment will be carried out using 2 different types of electrodes to determine the better one for water purification and ozone production.

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