Comparison Double Dielectric Barrier Using Perforated Aluminium for Ozone Generation

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Abstract*- Ozone generation has widely known—may replace chlorine compounds in various applications including wastewater treatment, polluted air processing, antimicrobial, bacterial inactivation, semiconductor oxidation, and serve as disinfectan. This study mainly focuses on comparison of different dielectric materials performances using perforated aluminium to obtain high concentrated ozone. Perforated aluminium with sharp edges used for ozone generation as electrode. Dielectric barrier discharge (DBD) using glass and 96% alumina ceramic have been chosen for limiting discharge current due to its low thermal conductivity and low dielectrics loss when high breakdown voltage occur. Double dielectric barrier using perforated aluminium has been observed using 96% alumina and quartz glass, both within 2 mm thickness. Ozone concentration of alumina ceramic dielectric for 0.5mm space gap was higher than quart glass. However, for 1mm space gap, ozone concentration using quart glass was higher than alumina ceramic. These results lead to optimum condition for DBD using alumina ceramic is not more than 0,5mm space gap.

Index Terms—Dielectric Barrier Discharge, Ozone, Dielectric Material.

I. INTRODUCTION

Ozone is a powerful oxidizing agent made of stable molecular oxygen (O2) that can replace chlorine compounds in various applications including wastewater treatment, polluted air processing, antimicrobial, bacterial inactivation, semiconductor oxidation, and as a disinfectant [1][2][3][4]. However, the remaining of ozone will return to natural oxygen that makes environment unaffected by pollution from its byproducts [5].

Ozone is unstable therefore it may decompose gradually (in minutes) at room temperature and quickly (<1 second) at higher temperatures [1]. Due to this instability, ozone has to be made in place for various desired applications. Based on ozone capabilities that recognized, this research on ozone continues to be improved.

Ozone may be produced by several methods such as electrical discharge, optochemical reaction and UV radiation. Electrical discharge is the most generally used method of ozone generation. Among them are corona discharge, gliding arc discharge and dielectric barrier discharge. The most commonly used method for ozone generation is the dielectric barrier discharge (DBD) that operated at atmospheric pressure [6][7][8]. This structure consists of two separated electrodes with gap distances on either or both sides using a dielectric material. This system produces stable non-thermal plasma and under atmospheric pressure so it is a good method for ozone production [9] [10]. This method was also well-known that the most cost effective method[11].

The dielectric barrier that contained above the grounded electrode is used to limit the discharge current, prevents the transition of the DBD discharge to an arc discharge, to make sure that stable non-equilibrium plasma can be generated even under atmospheric pressure, that is appropriate for ozone generation [12][13][14][15]. Because of that, dielectric barrier that contained above grounded electrode may serve to distribute the discharge evenly throughout the electrode path area and increase ozone generation by using low-conductivity dielectric material. In addition, ozone generation may also be affected from gap distances, electrode material, gas type, voltage, power supply, gas input and dielectric material [16][17][18].

The method of ozone forming may dissociate the oxygen molecules into atoms so that oxygen molecules and third particle (usually oxygen or nitrogen if air is injected) collide and form ozone immediately. The ozone formed would have high-energy electrons between 1-10 eV that generated in discharge removal area of DBD [10]. Ozone formation mechanism of ionization and recombination includes both dissociation and association [19]. The processes start by electron bombardment of O_2 molecules in the discharge region

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resulting in oxygen atoms and combine the electron with oxygen molecules to create ozone. The major reactions for ozone formation are showed as follows:

$$e + O_2 \rightarrow O + O + e \tag{1}$$
$$O + O_2 + M \rightarrow O_3 + M \tag{2}$$

Where M is a third collision partner that has a role in the process of energy absorption but does not react to chemistry so that the distribution of high energies electrons determines the amount of ozone formed. At the same time the formation of ozone occurs with the occurrence of ozone decomposition. The decomposition of ozone takes place through the reaction as follows:

$$O + O_3 \rightarrow O_2 + O_2 \tag{3}$$
$$e + O_3 \rightarrow O_2 + O \tag{4}$$

From Eq. (1) to Eq. (4) show that opposition between ozone generation and ozone decomposition around process ozone production [11].

Material dielectric using glass and alumina that have been known for low conductivity and low temperature plasma that enhance ozone generation efficiency [7]. The objective of this study is to investigate the optimum conditions for the effective ozone concentration in dielectric barrier discharge, measurements of ozone concentration using perforated aluminium were carried out for various conditions of gap spacing, dielectric material and voltage.

II. EXPERIMENTAL SETUP

The experimental setup used to study the ability of a perforated aluminium electrode to generate ozone. The plane-plane spesification of perforated aluminium electrode sheet are 1.5 mm thickness, 1 mm diameter hole. Gap distances between dielectric barriers are 1 mm and 0.5 mm. This study using variation of dielectric barrier which are glass and alumina ceramic for double dielectric barrier which have known for their lower dielectric breakdown [20]. Dielectric barrier procedure was assumed, with both sides having one perforated aluminium electrode sheet (7.7 cm length and 7.7 cm width) located between aluminium foil and dielectric barrier (Fig.1). The aluminium foil serves as high voltage electrode on one side of reactor chamber and as ground electrode on the other side.

Glass sheet within 2 mm diameter was used as the dielectric barrier. The working gas (99.99% pure oxygen) with flowrate 1 L/min was injected through plasma chamber with ambient temperature and atmospheric pressure. Input voltage 18 kV and 19 kV at frequency of 50 Hz used to supply the reactor chamber. Dielectric barrier discharge (DBD) which using 50 Hz power source is a suitable choice [21].

The advantages of using low frequency include limiting current of the dielectric layer to the electrode effectively thereby stabilizing the discharge, and the availability of inexpensive and highly efficient solid-state power supply power supply [13].

High voltage probe *(Tektronix P6015A, 1000:1,3.0 pF, 100 MΩ)* for measuring input voltage was connected in parallel with the DBD reactor. The voltage applied to the electrodes was measured via voltage divider. The transported charges were measured by placing capacitor 0.22 mF between the grounded electrodes and ground, respectively. The voltage waveform were recorded by Picoscope 3206B (200 MHz, 500 MS/s).

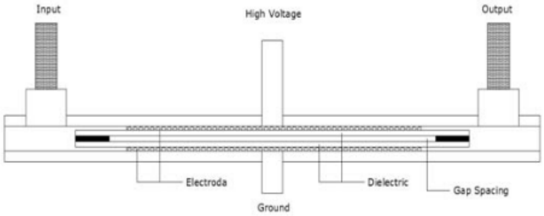

Figure 1. Dielectric Barrier Discharge Chamber (DBD)

Two parallel-perforated aluminium electrodes were placed on each side of the dielectric with barrier alumina 96% or glass. The alumina had an Al2O3 content of 96%, thermal conductivity 27,3w/m.k; insulation resistance of 22.5 kV, alumina ceramic has characteristic of high performance to achieve thermal efficiency. An electrode was connected to high voltage side and the other was connected to ground via a capacitor of suitable capacitance.

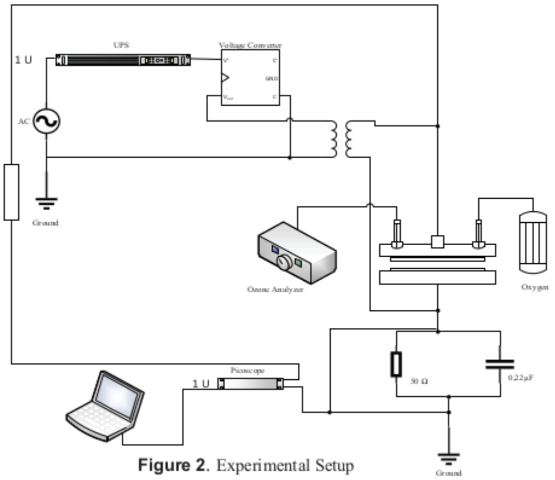

Figure 2. Experimental Setup

A 50-ohm current-limiting resistor was connected between output of transformer and reactor. The gas flowrate was maintained at 0.1 L/m and the pressure in the reactor was controlled by the needle valve in ozone analyzer (BMT 964) and also measured the outlet ozone concentration. Ozone generation was conducted using a planar type chamber made by acrylic or polymethyl methacrylate and using perforated aluminium as electrode with glass and alumina ceramic as the

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dielectric material. This system was operated at atmospheric pressure and ambient temperature. The advantages of planar chamber shape are easy modification for air gap with filler materials, simple construction, simple replacement and arrangement for different type electrode and dielectric [20].

III. RESULTS AND DISCUSSION

Dielectric material used may affect high ozone produced and ozone concentrations as it allows to contribute to the limitation of rising gas temperatures in the discharge area requiring dielectric materials that have low thermal conductivity and dielectric constants. Based on Sung et.al, using 1 mm thick quartz glass disk (Q) as dielectric material with relative dielectric constant of about 3.8 and 1 mm thick alumina disk (ALO) with relative constant dielectric about 8.5 using the oxygen and dry air having constant flow rate of 3L / min. The ozone concentration obtained with the alumina disk is higher than the quartz glass one, as each length of the slit decreases by increasing discharge voltage. Thermal conductivity of alumina disk is about 15 times bigger than quartz glass. Previous case with alumina disc, relatively high ozone product obtained only when the length of short gap [16]. However, it needs more investigation about dielectric material that may be used for ozone generation and ozone yields.

This experiment using perforated aluminium that would be better in ozone generation due to its sharp-edged holes, which makes electric field strength in discharge region become high. Based on Buntat et.al, to produces improve glow discharge stability at atmospheric pressure by using the discharge configuration with perforated aluminium electrodes that means effective of improving the ozone generation [22]. However, perforated aluminium using different double dielectric (glass and alumina ceramic 96%) has been observed, respectively.

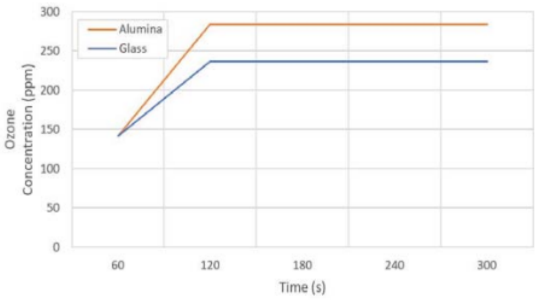

Figure 3. Ozone concentration using alumina and glass in 0,5 mm space gap at 19kV input voltage

Ozone concentration obtained from dielectric materials (glass and alumina Ceramic 96%) shows inversely proportional result when using different gap length between dielectric. For glass dielectric, optimum ozone concentration obtained 236.5 ppm with 0.5 mm and 1 mm gap length. It different with alumina dielectric that ozone concentration obtained 283.8 ppm with gap length 0.5 mm (Fig. 3) and 141.9 ppm with gap length 1 mm (Fig.4).

These result inversely proportional when gap spacing changed from 0,5 mm to 1 mm. At the same condition using perforated aluminium and glass dielectric has higher ozone concentration than alumina dielectric within 1 mm space gap. However, when alumina dielectric was used, ozone concentration become higher than glass with 0,5 mm space gap.

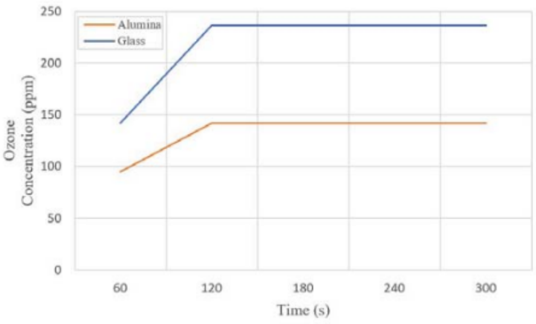

Figure 4. Ozone Concentration using alumina and glass in 1 mm space gap at 19kV

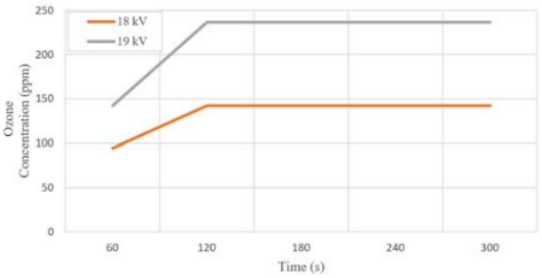

Figure 5. Ozone Concentration using alumina in 1 mm gap spacing at 18 kV and 19 kV

These indicate alumina has good condition for ozone concentration when using gap spacing lower than 1mm. These results in accordance with Sung et.al who used alumina disk, then ozone concentration decreased as gap length getting longer. Dielectric material has consumed power that converted into heat whereby not only the temperature in the dielectric material but also the temperature in the discharge region increases. Sung et.al assumed that discharge power became high in conditions where alumina disk of which the dielectric constant was larger than that of the quartz disk was used as a dielectric material even under the same discharge condition. The discharge power increased as the increasing of discharge voltage and the gap length [16]. Increasing the gap space may increase the power consumption of the system [23]. These mean that ozone concentration increases when decreasing discharge power and gap length.

One of factor that may affect high ozone concentration is limitation of ozone dissociation at discharge region; another factor is the gap distance between dielectric materials. The dissociation reaction of oxygen and ozone molecules, by the impact of electrons, depends on the reduced electric field (E/n, where E is electric field and n is particle density) [16]. Ozone dissociation process may affect decomposition ozone rapidly.

Based on these results, applied high-voltage will increase ozone concentration (Fig.5). The increasing voltage will increase ozone concentration due to high voltage applied to dielectric barrier discharge. Then these lead to high electron avalanche recombined with other molecules that formed ozone and high electronegativity of oxygen in which play important role in this observation.

The result shows that ozone concentration obtained 236,5 ppm and 283,5 ppm is suitable for home usage, sterilization vegetable with ozone concentration in this range. Zhao et al used gaseous ozone (6.7 ppm for 6 h) as a disinfectant in reducing microbial populations in ground black pepper, observing a 3–6 log reduction depending on the moisture content material [24]. Selma et al suggested that the ozone treatments at levels of 1.6 and 2.2 ppm for 1 min reduced Shigella sonnei population in water by 3.7 and 5.6 log CFU ml^{-1}[25]. Najafi et al assumed for reducing both coliform and Staphlyococcus aureus populations on date fruits which minimum of 1h ozone treatment at 5 ppm could be effectively used, however for elimination of the total mesophilic bacteria as well as yeast/mould present that still need longer exposure times were required [26]. Cullen et al have study that using ozone 5 ppm ($p < 0.05$) in 60 min for Escherichia coli and S. aureus were not found on cultured plates inoculated with the treated samples after treatment. There are most studies have been conducted for Gram-negative bacteria (E. coli), which give the impression to be more resistant than Gram-positive bacteria. Bacteria are also more sensitive than yeasts and fungi [27]. However, based on those all studies that ozone is safe for food due to one of potential advantages is that excess ozone auto-decomposes rapidly to produce oxygen and thus leaves no residues in food.

IV. CONCLUSION

Dielectric barrier discharge using alumina and glass has been conducted in this paper. The optimum conditions for the effective ozone concentration in dielectric barrier discharge, measurements of ozone concentration using perforated aluminium were carried out for various conditions of gap spacing, dielectric material and voltage. The use of perforated aluminium as sharp edges electrodes was to increase ozone concentration. It was found that maximum ozone concentration 236,5 ppm when using glass with 1 mm gap spacing and 283,5 ppm when using 236,5 ppm using alumina with gap spacing 0,5 mm. This result suitable for home usage and sterilization vegetable with ozone concentration in this range due to one of the potential advantages is that excess ozone auto-decomposes rapidly to produce oxygen and thus leaves no residues in food.

ACKNOWLEDGEMENTS

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