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Effective Medical Ozone Production Using Mesh Electrodes in Double Dielectric Barrier Type Plasma Generators

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Abstract. One of the most effective ways to produce ozone is to use Dielectric barrier discharge plasma (DBDP). Various geometric configurations can be used to produce ozone. However, it is necessary to develop a reactor to produce medical ozone. Medical ozone can be produced using Double DBD reactor with an oxygen source. The aim of this paper is to carry out an experimental analysis of ozone concentrations which produced using DDBD reactor. The reactor used cylindrical-cylindrical electrode configurations made from copper mesh. The high AC voltage was applied in the range between 0,5 to 3,2 kV and the frequency of 50 Hz. Oxygen (O_2) is used as input gas source with several variations in flow rates from 0,2 to 1 liter/min. The results show that air flow rate input and voltage can affect ozone concentration. Ozone concentration can be increased by increasing the voltage or decreasing the flow rate. The results also showed that DDBD with this configuration could produce medical ozone concentration from 24 – 768 ppm which could be applied further in the medical field.

INTRODUCTION

Ozone (O_3) is one of the most reactive oxidants and is an excellent disinfectant [1]. Ozone can be produced using UV radiation, Corona Discharges, or dielectric barrier discharges (DBD) [2,3]. Electrical discharge (spark) will separate oxygen molecules into two oxygen atoms and then react with oxygen molecules to form ozone molecules [4].

Ozone has many benefits. Ozone can be used to preserve various types of food ingredients, fish preservation, air purification, and several fields of dentistry and medicine [5-8]. As an oxidant, ozone has powerful antimicrobial properties against microorganisms such as bacteria, viruses and protozoa. These properties cause ozone to have many benefits, especially in the medical field, such as disinfecting, treating skin diseases, and healing various types of wounds [9-11].

DBD is the most effective way to produce ozone because it requires a lower initial voltage and less power consumption. Discharge occurs homogeneously throughout the reactor volume and produces a relatively low temperature so it does not require a cooling system [13,14]. Research to compare ozone production from input gas in the form of oxygen and air using a spiral-cylinder geometry DBD reactor, the relationship between the flow rate of the input gas to the ozone concentration, and the influence of the mesh electrode on the DBD rector has been carried out in reference [15-19].

There is a development of DBD, namely DDBD (Double Dielectric Barrier Discharge). DDBD has a double barrier between the electrodes, so there is no contact between the input air and the electrodes during the ozone production process. So that the ozone produced by the DDBD reactor is pure. DDBD can also produce higher ozone concentrations compared with DBD [20,21].

There is no further research about the production of pure ozone or medical ozone using DDBD reactor with mesh-mesh electrode configuration. Therefore, this research will characterize the voltage and flow rate to obtain the

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optimum medical ozone concentration when producing ozone using DDBD with Oxygen as an input gas and electrode configuration made from copper mesh.

EXPERIMENTAL METHODS

This research uses DDBD with cylindrical geometries and copper mesh electrodes as in Figure 2. Figure 1 is a setup of tools used in the experiment. The dielectric barrier is a glass tube 18 cm long and 0.275 cm thick. The outer diameter of the tube is 4 cm and the inner diameter is 2.3 cm. The electrodes used are copper mesh arranged into cylinders with a length of 9 cm. The two electrodes are connected to an AC voltage source with voltage variations of 0.5 kV - 3.2 kV and a frequency of 50Hz. Electrodes are also connected to ammeters and multimeters so that the research parameters can be identified. At both ends of the reactor, holes are facing upward for input and output gases. The inlet gas port is connected with a hose to the oxygen cylinder, while the output is connected with the hose to the KI solution. The hose is made of PU (Poly Urethan). The inlet oxygen flow rate used is 0.2-1 L / min with an interval of 0.2 L / min.

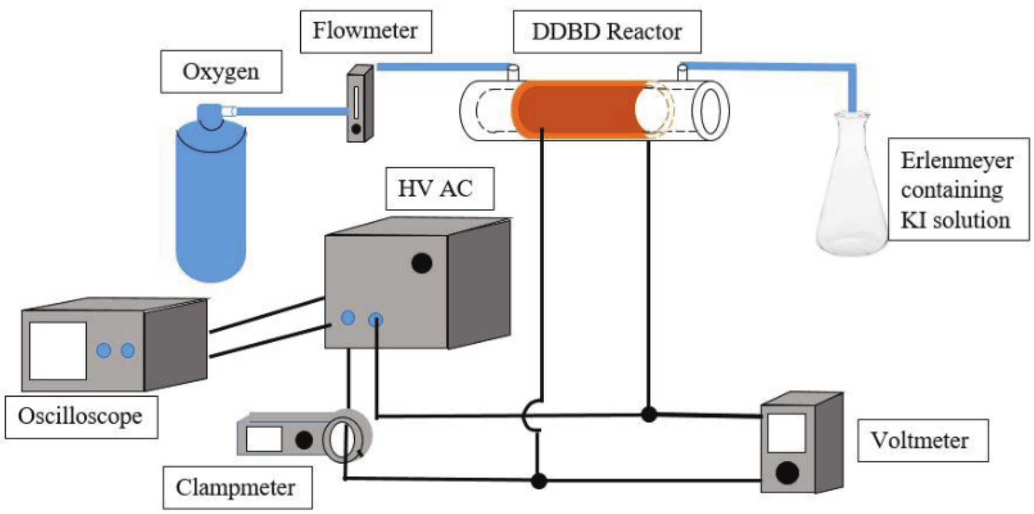

FIGURE 1. Research tools set-up scheme

Ozone that has been produced is titrated using sodium thiosulfate solution to determine the ozone concentration. The ozone concentration is then calculated using the equation:

$$C_{ozon} = \frac{R x V_t x N_t}{V_{gas}} \tag{1}$$

C_{ozon} is the concentration of ozone (gram / L), R is the ratio of analytical moles and reactants in a balanced chemical equation, Vt is the volume of the titrant (L), Nt is the normality of sodium thiosulfate (mol / L) and Vgas is the volume of gas (oxygen) which is used [22].

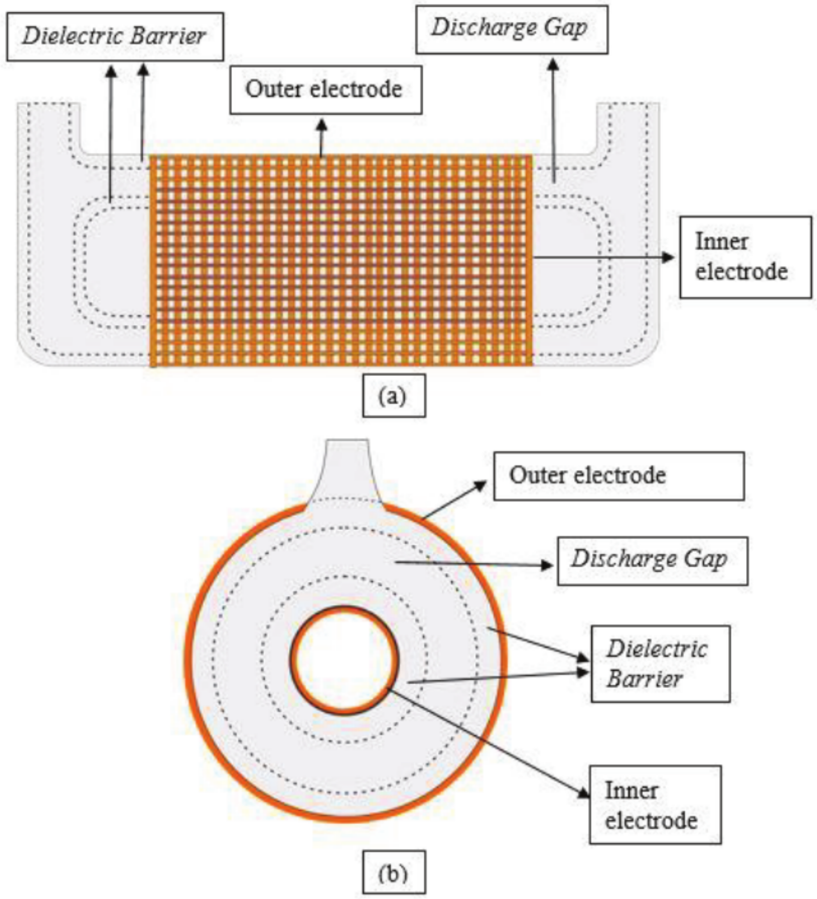

FIGURE 2. The DDBD reactor scheme uses meshed plate electrodes (a) side view; (b) front view.

RESULT AND DISCUSSION

Current Characteristics as a Function of Voltage

Current characteristics as a function of voltage in the DDBD reactor can be seen in Figure 3. The graph shows that the increase in current occurs when the voltage is increased. This happens because the higher voltage creates a greater potential difference and then creates a stronger electric field. The electric field then accelerates the movement of charged particles which then cause charged particles to collide and trigger excitation, dexitation, ionization, and the process of recombination and producing electric charges. An electric charge that moves each unit of time produces an electric current [21,23].

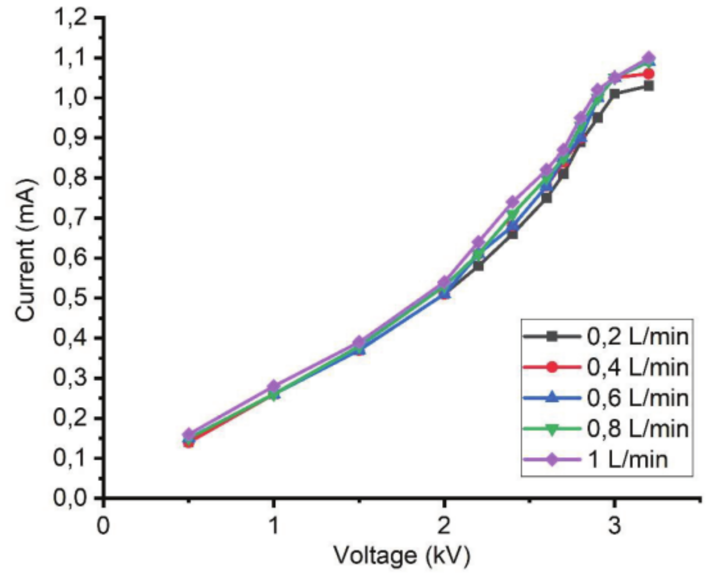

FIGURE 3. Graph of current characteristics as a function of voltage.

Effects of Voltage on Ozone Concentration

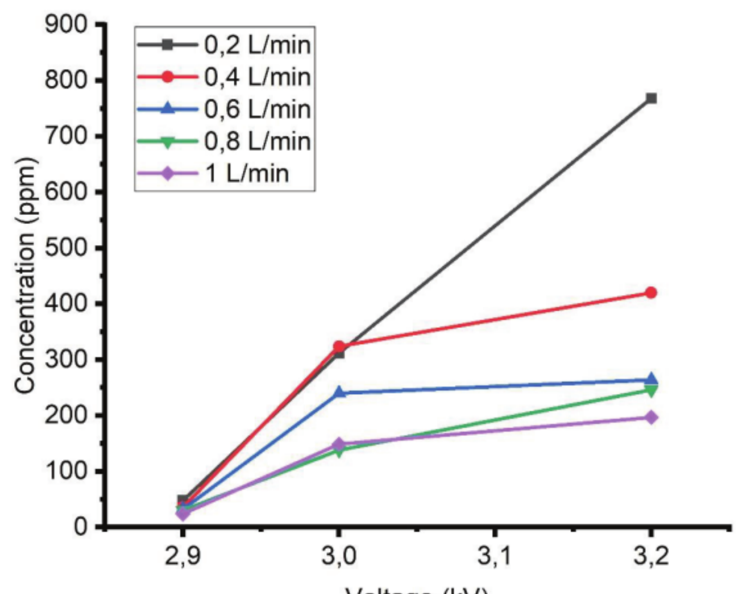

FIGURE 4. Graph of concentration characteristics as a function of voltage

The KI solution turns into a brownish-yellow KIO_3 solution when the KI solution is reacted with ozone, and the color is more concentrated when the voltage is increased.

The effect of voltage on ozone concentration at several flow rates can be seen in Figure 4. Voltage is one of the parameters that can affect ozone production in this study, the higher the voltage applied, the greater the potential difference between the electrodes. The greater this potential difference causes more and more charged particles to have enough energy to ionize or excite oxygen molecules when collisions occur. The collision results in the formation of more ozone [24]. This research is in accordance with the research conducted by Restiwijaya et al [25].

Effect of Flow Rate on Ozone Concentration

Ozone concentration is reduced by increasing the flow rate as shown in Figure 5. The results of this study are in accordance with a research by Zain, et al [21]. The higher flow rate will cause the gas residence time in the reactor to be reduced. When oxygen is in the reactor the ozone formation reaction occurs from the dissociation of O_2 from collisions with electrons (R1), which then occurs three-body reaction (R2).

$$O_2 + e \rightarrow 2O + e \qquad \text{(R1)}$$

$$O + O_2 + O_2 \rightarrow O_3 + O_2 \qquad \text{(R2)}$$

The reaction rate of R2 is slower when compared to R1. So that when the flow rate is increased the O atom produced by the R1 reaction runs out faster along with the flow rate of the gas that comes out faster, so that the ozone formed through the R2 reaction is less because there is only a little O in the reactor [21].

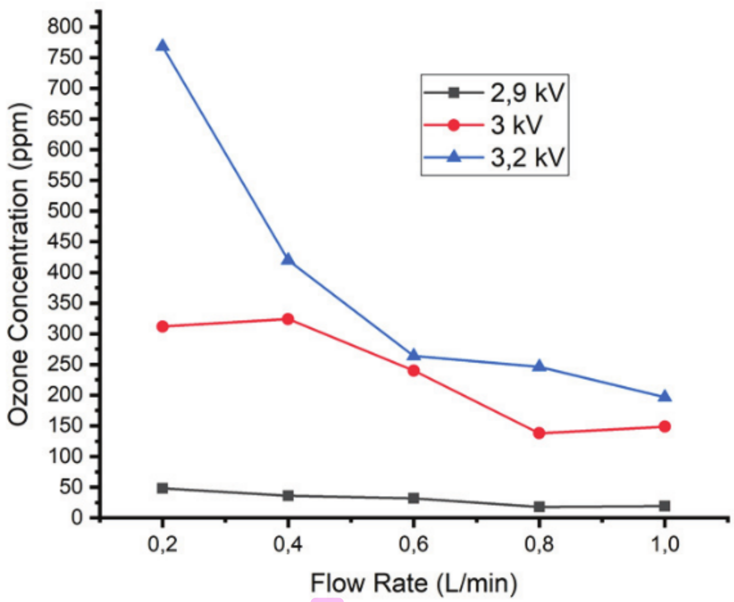

FIGURE 5. Graph of ozone concentration as a function of flow rate

Application in the Medical Field

When used in certain diseases or conditions, ozone will have the same effect or impact throughout the world, wherever ozone is used. The application of an inappropriate method or dose will cause side effects or ozone ineffectiveness. Therefore, a protocol was made as a basis for standards and guidelines for the use of medical ozone. One of the guidelines is related to the concentration or dose of ozone needed for therapy or treatment as in Table 1.

In this study, at 2.9 kV with a flow rate of 1 L / min and 0.8 L / min, the optimum concentration of medical ozone was 24 ppm and 30 ppm. So that this configuration can be applied for after wound cleansing, wound healing, and burn stages 1 and 2 treatments.

TABLE 1. Topical application of medical ozone (Hansler, et al 2012)

Indication	Ozone Concentration	Form of Application	Treatment Time	Treatment Frequency
Decubitus ulcers	80-100 µg/ml in the beginning	Low pressure suction cup	2-10 min	Daily first, then 1-2x per week
After wound cleansing	20-30 µg/ml	Low pressure boot (or plastic bag)	10-20 min	Daily first, then 1-2x per week
Diabetic gangrene	80-100 µg/ml in the beginning			
After wound cleansing	20-30 µg/ml	Plastic bag (not low pressure!)	10-20 min	Daily first, then 1-2x per week
Ulcus cruris	80-100 µg/ml in the beginning			
Wound cleansing				
Wound Healing	20-30 µg/ml	Compresses + rinsing with ozone water	1-5 min	Several times daily
Burn stage 1 and 2	20-30 µg/ml	Plastic bag,	10-20 min	First 1-2x per day
		compresses + rinsing with ozone water	1-5 min	Several times per day

CONCLUSION

DDBD reactors can be used to produce medical ozone where the higher the voltage, the higher the current at the reactor and the concentration of ozone produced. Ozone concentration can also be increased by reducing the input oxygen flow rate. The configuration in the research carried out can produce 24 ppm and 30 ppm ozone concentrations using a voltage of 2.9 kV at a flow rate of 1 L / min and 0.8 L / min. This concentration can be applied in the medical field, which is for after wound cleansing, wound healing, and burn stages 1 and 2.

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