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Medical Ozone Machine by Using DDBD Reactor for Low Dose Standard

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Abstract:- Medical ozone has been widely used for health and medicine. The best technology for producing medical ozone currently is the Double Dielectric Barrier Discharge (DDBD) plasma reactor. This research uses DDBD to obtain the doses needed for medical purposes to meet the standards of the Madrid declaration. This reactor uses two aluminium electrodes with mesh-mesh configuration . High pulse AC voltage is applied between 0 and 4000 V. The pulse frequency at power are of 60 Hz and 70 Hz. DDBD plasma reactor to supply medical oxygen with flow rate variations from 0.2 L/min to 0.8 L/min. From this research, it was found that the concentration and capacity of ozone produced by the DDBD reactor was higher when using a higher operating voltage. Apart from that, the greater the flow rate of oxygen supplied to the reactor, the greater the concentration and capacity of medical ozone produced. Use in the medical world requires precise dosage. From many trials of variations in oxygen flow rate, operating voltage and pulse frequency, ozone doses were obtained that were in accordance with the ozone dose range based on the Madrid declaration. A choice of variations of the required parameters is provided on a touch screen to facilitate treatment for patients

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Keywords: medical ozone, ozone dose, double dielectric barrier discharge, Madrid declaration,

1. Introduction

The development of plasma technology in the medical field is very rapid. One of them is double dielectric barrier discharge (DDBD) technology for the formation of medical ozone [1,2,3,4]. Ozone can be produced from electrical discharges. Oxygen molecules separate into single oxygen and then react with oxygen molecules to form ozone [5]. Research on the use of ozone in medicine has shown success. Ozone has been proven to kill bacteria, viruses and fungi. Ozone also has the potential to accelerate tissue epithelialization and stimulate cell regeneration, resulting in medical ozone in the treatment of disease [6,7,8,9,10]. The use of DDBD reactors is highly recommended in producing medical ozone because this reactor is considered to meet specifications. The main condition for the formation of medical ozone is that pure oxygen in the reactor does not come into direct contact with the electrodes. DDBD has two dielectric barriers. Between the two diffusers there is a space which functions as a place for pure oxygen to flow and when it reacts with an electric field it will produce high purity medical ozone [2,11].The use of medical ozone must comply with the dosage set by the world ozone committee. This was determined by the International Scientific Committee of Ozone Therapy in 2020, through the Madrid Declaration on Ozone Therapy [12].

The use of ozone in appropriate doses for precise treatment has been accommodated by the Madrid Declaration. Treatment according to this dosage is what gives good results. From several reported studies, the successful use of medical ozone shows good results. The reason is, medical ozone has the ability to kill bacteria, viruses and fungi. In addition to the oxidation of oxidative stress, ozone can accelerate tissue growth factors, circulation, epithelialization and stimulate cell regeneration [13] The use of ozone as a therapeutic agent for various disorders [14]. In addition, stimulating the antioxidant response in cardiomyopathy patients [15] and increasing hemoglobin oxygenation in diabetes patients can also be achieved with ozone therapy [16]. Ozone liver damage can be protected by the use of medical ozone by carbon terachloride and renal ischemicreperfusion. This occurs because it stimulates the oxidative conditioning mechanisms of the endogenous antioxidant system and modulates nitric oxide (NO) [17]. Ozone therapy can be a therapy for diabetes mellitus. There are two functions, namely as an antioxidant system so it is considered as an insulin adjuvant and also to prevent and relieve nephropathy that occurs due to DM through the process of oxidative stress [18].

The use of ozone for medicine has very different standards from the application of ozone for industry. Ozone gas used for industrial oxygen sources can be taken from free air, while for medical purposes pure medical standard oxygen is used [19]. Ozone reactors for industry are allowed to use dielectric barrier discharge (DBD), while for medical purposes they must use DDBD reactors because these reactors are considered to be of higher quality as medical reactors because between the two barriers there is a space that functions as a place for pure oxygen to flow. In this chamber, the high electric field accelerates the electrons and plasma is formed. Energetic electrons are involved in collisions with oxygen molecules, oxygen dissociates and reacts with oxygen molecules to produce high purity medical ozone. [12,20].

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Because it is related to patients, medical ozone in its application requires a very high level of dosage accuracy. From a search of the literature review, only a few previous studies have linked the development of DDBD as an ozone producer to the capacity and dose of ozone required for therapy.

This paper reports the results of medical ozone production from the DDBD reactor which is associated with the use of medical ozone which requires meeting the dosage determined by the world ozone committee through the Madrid Declaration on Ozone Therapy. The correct dose will be reported on the influence of operating voltage, oxygen flow rate, voltage pulse frequency, and work cycle

2. Objectives

This research aims to obtain a dose of ozone produced by a medical ozone generator that meets the standards for ozone therapy stated in the Madrid Declaration. This standard is obtained by varying the oxygen flow rate and operating voltage. The ozone concentration produced by the DDBD reactor was measured. Measuring the ozone concentration is followed by determining the ozone capacity and finally, with a certain flow rate and certain voltage, a medical ozone dose is obtained that meets the Madrid Declaration ozone therapy standards.

3. Methods

Figure 1 shows a double dielectric barrier discharge (DDBD) reactor. The reactor is made of borosilicate glass (pyrex) with a length of 19 cm and a thickness of 0.2 cm. In the reactor there are two tube-shaped barriers. The outer diameter of the tube is 4 cm and the inner diameter is 2 cm. The electrodes used are aluminum mesh sheets. The outer electrode is cylindrical, 15 cm long and 15.5 cm wide, shaped like a cylinder and covers the pyrex tube on the outside. The inner electrode is also made of aluminum mesh with a length of 15 cm and a width of 9 cm and is cylindrical and enclosed in an inner pyrex tube. To generate plasma with medical oxygen gas, an AC pulse voltage source with a voltage variation of 0 V – 4000 V and a frequency of 60 Hz is connected to both electrodes. The DDBD reactor tube is equipped with a tube-shaped channel facing upwards to enter oxygen gas (O_2) and output a mixture of oxygen and ozone gas (O_2 + O_3). The gas inlet port made in the reactor is connected by a hose to the oxygen cylinder. On the other hand, the outlet port is connected to a polyurethane hose to the ozone monitor. The ozone concentration produced by the DDBD reactor was measured on the ozone monitor. The input gas is medical standard pure oxygen with a purity of 99.5%. In this study the flow rate used was 0.2 L/minute – 0.8 L/minute. Medical oozone products can be calculated in terms of capacity and dosage. The concentration, capacity and dose of medical ozone are adjusted to the rules of the Madrid Declaration on Ozone Therapy 2020 [13], in order to find the right dose of medical ozone for therapy.

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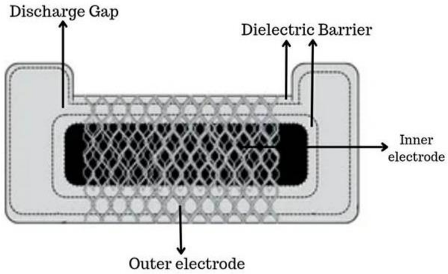

Fig.1. DDBD sketch as a medical ozone reactor with aluminum mesh electrodes

Ozone capacity can be calculated using the formula [15]:

$$Cp_{O_3} = C_{O_3} \times flowrate \quad (1)$$

where Cp_{O_3} is the ozone capacity in grams/hour or micrograms/minute and flowrate is the O_2 flowrate, L/hour or L/min. Meanwhile, the ozone dose can be calculated using the formula [5]:

$$Dosis\ O_3 = Cp_{O_3} \times t_{expose} \quad (2)$$

where t_{expose} is the ozone exposure ini minutes. The realization of a medical ozone generator or medical ozone machine is shown in Figure 3 and experimental set up of this research is showns in Figure 2. The medical ozone machine is equipped with a touch screen that can set the operational voltage, exposure time and desired dose to be exposed to the patient. The medical ozone machine body measures 90 cm high, 60 cm wide and 40 cm thick. This height is made to suit direct therapy on the patient. The oxygen cylinder is placed inside the machine body so that it is not visible from the outside, so it is hoped that it can provide comfort for the patient. The machine is also equipped with wheels so it is easy to move as needed.

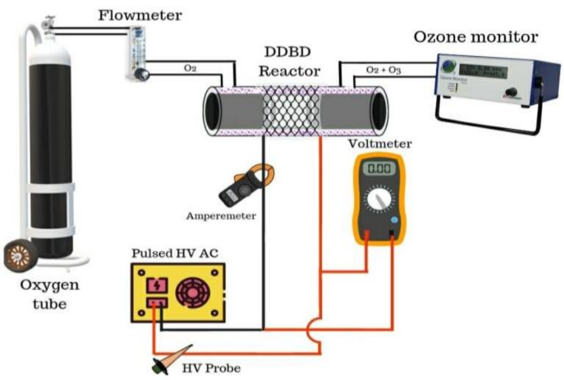

Fig.2. Experimental scheme for characterization of medical ozone generators manufactured with DDBD Plasma

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The use of ozone must be well controlled so as not to pollute the treatment room. So the ozone generating machine is equipped with an ozone destroyer. The remaining ozone, for example in the bagging treatment, is channeled back into the machine and enters the ozone destroyer.

(b)

(a)

Fig.3. Medical ozone machine (MOM) full body (a),MOM's touche sreen(b)

4. Results and Duscussion

This research uses a double dielectric barrier discharge (DDBD) reactor made from medical standard borosilicate glass (pyrex) with a cylindrical mesh electrode configuration made from aluminum plates to produce a dose of medical ozone that meets the criteria of the Madrid Declaration on Ozone Therapy 2020. This research resulted in several discussions related to medical ozone generators, including the effect of voltage on input power, the effect of voltage on ozone concentration and capacity, the effect of oxygen flow rate on ozone concentration, the effect of oxygen flow rate on ozone capacity.

4.1. Effect of Voltage on Ozone Concentration and Ozone Capacity

To see the effect of voltage on ozone concentration and ozone capacity, this research uses a fixed frequency of 60 Hz for several oxygen gas flow rates. Figure 4 shows the effect of operating voltage on the resulting ozone concentration. Ozone concentrations can be detected directly on an ozone monitor, or determined by titration. Operational voltage is one of the parameters that can influence ozone production. It can be seen in Figure 4 that the higher the voltage applied, the greater the ozone concentration produced. This is because the potential difference between the electrodes is also getting higher. The greater the potential difference

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causes more charged particles to have sufficient energy to ionize, disassociate, excite oxygen molecules when a collision occurs. Ozone is formed due to the collision of energetic electrons. This research is in accordance with that carried out several researcher [1,2,5,21]

The formation of ozone in the DDBD reactor is very dependent on the AC pulse power used. Frequency and duty cycle as well as voltage are very influential. When a high AC voltage is applied to the reactor, the initial electrons will be accelerated in an alternating high electric field. Energetic electrons are involved in collisions with oxygen molecules in the reactor plasma zone [5]. The collision process occurs in a space bounded by two dielectric barrier materials [2,5]. The ozone formation chamber contains two electrodes. The inner electrode attaches to the inner pyrex tube (dielectric) and the outer electrode attaches to the outer dielectric tube (outer electrode). Pulse electric voltage gives rise to electric dipoles in the dielectric material and collisions between plasma species in the plasma chamber. This process provides higher ozone production with higher operating voltage. Also the concentration will be higher with a greater oxygen gas flow rate. The things explained above can be seen in Figure 4.

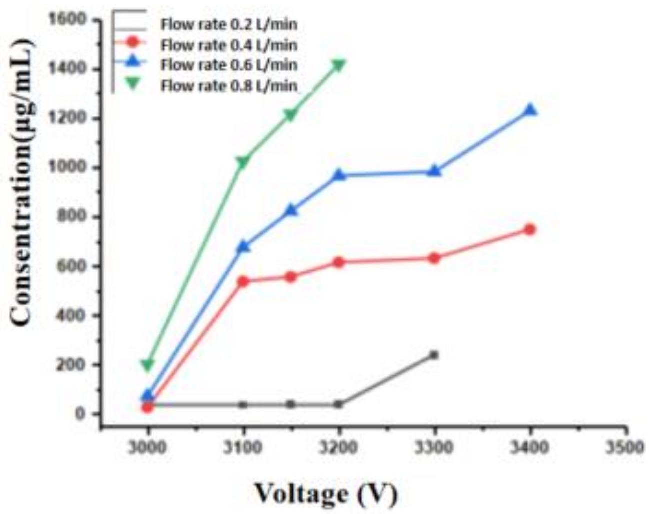

Fig.4. Inluence of voltage on ozone capacity for a pulse frequency of 60 Hz

In the DDBD reactor, ozone formation is largely caused by the process of energetic electron collisions in the active plasma zone in the reactor. When a high AC voltage is applied to the reactor, initial electron acceleration will occur. Energetic electrons will collide with oxygen molecules. This collision process results in ionization, dissociation, doubling of electrons. The many collisions between energetic electrons produce ions and free radicals. Radicals and ions are highly reactive species. These reactive species very easily interact with each other and produce new O_3 species.

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The formation of O_3 or ozone begins with dissociation (R1) by the free-electron impact dissociation of oxygen molecules [2].

$$e^- + O_2 \rightarrow 2O^* + e^- \quad \text{(R1)}$$

The O-atom dissociation fragments then react with oxygen molecules to form ozone through the following reaction:

$$O^* + O_2 + M \rightarrow O_3 + M \quad \text{(R2),}$$

where M is another gas molecule.

Figure 5 shows the effect of operational voltage on the capacity of ozone produced by medical ozone generating machines. From this figure it can be seen that the ozone capacity increases with increasing operating voltage.

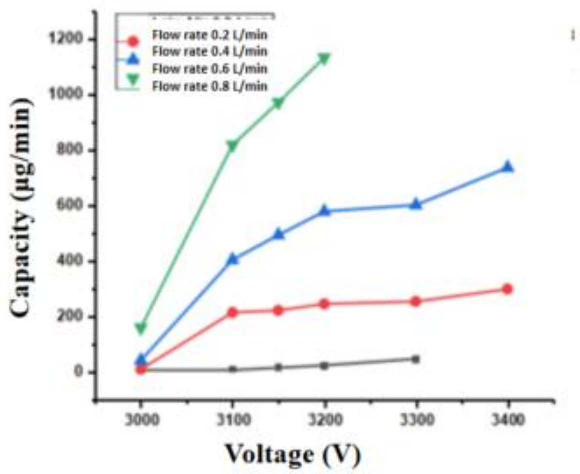

Fig.5. Inluence of voltage on ozone capacity for a pulse frequency of 60 Hz

This trend applies to all oxygen flow rates from 0.2 L/min to 0.8 L/min with an interval of 0.2 L/min, for a power supply pulse frequency of 60 Hz. Ozone capacity is obtained using equation (1). The dose for treatment is obtained by multiplying the capacity and exposure time. The trend in the results of the influence of operating voltage on ozone capacity in this study is in line with several previous researchers [1,2].

4.2. Effect of Flow Rate on Ozone Concentration and Ozone Capacity

The effect of flow rate on ozone concentration at several voltages can be seen in Figure 6. This data was obtained operating the DDBD ozone reactor at a certain voltage. The oxygen flow rate is varied. From the experimental results it can be seen in the graph in Figure 6 that the operating voltage of 3000 V, flow rate of 0.2 L/min, 0.4 L/min, 0.6 L/min and 0.8 L/min obtained a still low concentration. In the standards provided by the Mardid Declaration [12]

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and the standard procedure of major autohemotherapy MAH [22] only three conditions can be used to produce medical ozone for therapy. An oxygen flow rate of 0.8 L/min with an operating voltage of 3000 V is too high for therapy. For other operating voltages (3100 V-3400 V) in the experiment, concentrations that were too high for therapeutic medical ozone were obtained. In this figure it can also be seen that the concentration is higher for the greater the flowrate. Another interesting thing is that there is a sharp concentration jump for voltage (3100 V-3400 V) and flow rate of 0.4 L/min, 0.6 L/min and 0.8 L/min. A jump from the order of tens of µg/mL to hundreds of µg/mL. Even at an operating voltage of 3200 V and an oxygen flow rate of 0.8 L/min, the resulting ozone concentration was 1400 µg/mL.

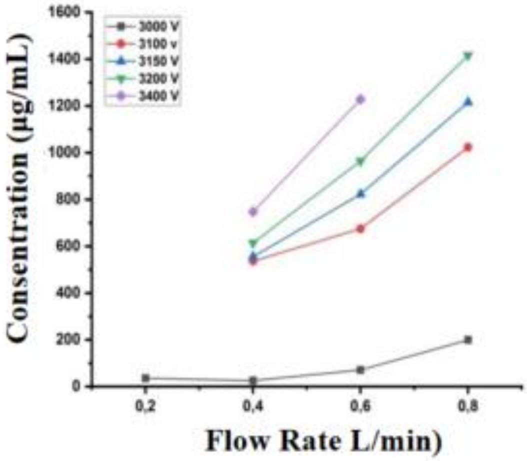

Fig.6. Ozone concentration as a function of flowrate for pulse frequency of 60 Hz

This concentration spike can occur due to the influence of the double dielectric used in the reactor. Apart from the dielectric material, an increase in flow rate also occurs, there is a change in the density of oxygen molecules flowing in the reactor. Nonlinear changes occur. The electric field at the inner and outer mesh electrodes also increases. The direction of the electric field changes rapidly due to the influence of frequency pulses from high voltage AC. Changes in the direction of the electric field result in changes in the electric poles and cause an increase in the breakdown voltage in the dielectric material. In DDBD, the buildup of charge on the dielectric material causes an opposing electric field that equalizes the electric field induced by the AC voltage applied in the initial half period and prevents the formation of new bands at the same position and half period [22]. These changes are thought to cause a jump in the resulting ozone concentration. This confirms the choice of operating voltage and flow rate that must be used in realizing medical ozone generating machines which generally require low concentrations, and low therapeutic doses as well.

4.3. Generating Dosage for Medical Ozone

The dosage of medical ozone for therapy for certain diseases is very specific. Medical ozone machines must be able to deliver that specific dose. The dose given to the patient can be given precisely by first determining the ozone capacity produced by the machine. The dose given to the patient is the product of the selected capacity of the machine and the exposure time. The

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longer the ozone flow time, the greater the dose the patient receives. By precisely measuring the machine's output capacity, the operator can determine the exposure time for delivery of the ozone dose. High doses or long exposure times may increase the risk of side effects. The DDBD reactor used in this research varies the flow rate, operating voltage and exposure time which can be set. In this study, the pulse frequency used was 60 Hz or 70 Hz. High doses or long exposure times may increase the risk of side effects. Therefore, it is important to comply with the guidelines for the use of ozone therapy, one of which is the guidelines for dosing medical ozone.

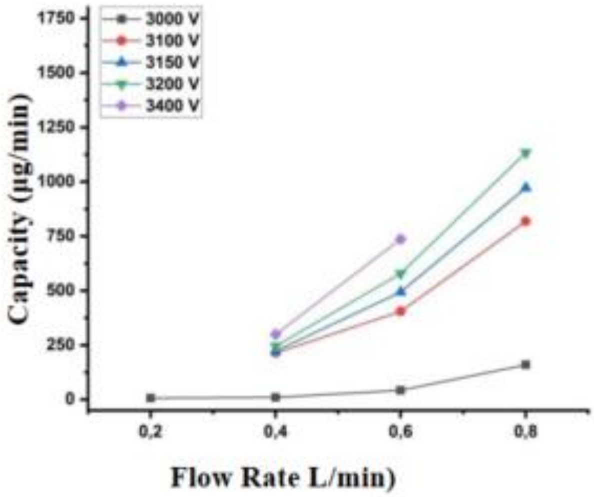

Fig.7. Ozone capacity as a function of flowrate for pulse frequency of 60 Hz

Guidelines regarding dosage are decided in congress periodically on a world scale. In this research, the 2020 Madrid Declaration was used as a guideline [12]. In this study, the medical ozone dose was obtained from characterization of the DDBD reactor by varying the voltage from 500 V to 3900 V with various flow rates and various time variations. However, to provide medical ozone doses suitable for large autohemotherapy applications, this reactor can produce it at voltages of 3000 V, 3100 V, and 3300 V at a frequency of 60 Hz, while at a frequency of 70 Hz it can produce it at voltages of 3600 V, 3700V, 3800V, and 3900V.

To provide an overview of the dose range, here we present published data specifically for doses in major athohemotherapy (MAH). Based on research that is widely referred to by ozone therapy practitioners, Viebahn-Hänsler, and León Fernández [23], reported that doses as below.

Table 1. Standard procedure of major autohemotherapy MAH [23].

MaH Standard Procedure: 50 mL of Blood + 50 mL of O_2/O_3 (or 100 mL of O_2/O_3 per 100 mL of Blood)			
Ozone concentration per mL of gas	10–20 µg/mL gas	30 µg/mL gas	maximum 40 µg/mL gas
Ozone concentration per mL of blood = biologically relevant concentration	10–20 µg/mL blood	30 µg/mL blood	40 µg/mL blood
Total ozone amount per 50 (100) mL blood	500–1000 µg per treatment	1500 µg per treatment	2000 µg per treatment

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Figure 8 shows the dose that can be produced by a medical ozone machine operating at a voltage of 3000 V with a flow rate between 0.2 L/min, 0.4 L/min, 0.6 L/min and 0.8 L/min. From the graph shown in the figure, a flow rate of 0.2 L/min - 0.6 L/min can provide the correct dose for the standard MAH and procedures shown in table 1 [23].

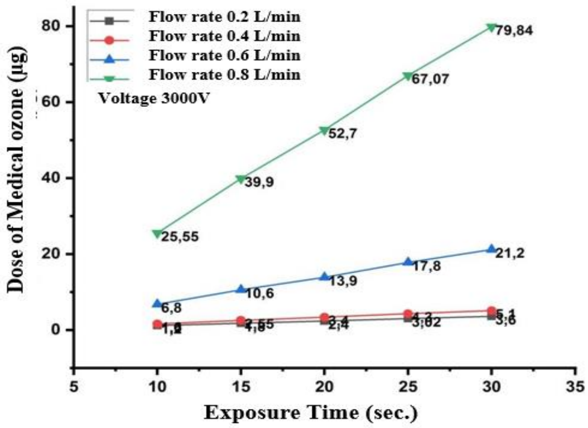

Fig.8. Doses as a function of time at a voltage of 3000 V, for several flowrate at 70 Hz Pulse Frequency.

According to the International Scientific Committee of Ozone Therapy, the Medical Ozone Generator (MOG) like other medical equipment must be certified. The precise ozone concentration produced by MOG is (1 µg/mL - 80 µg/mL).

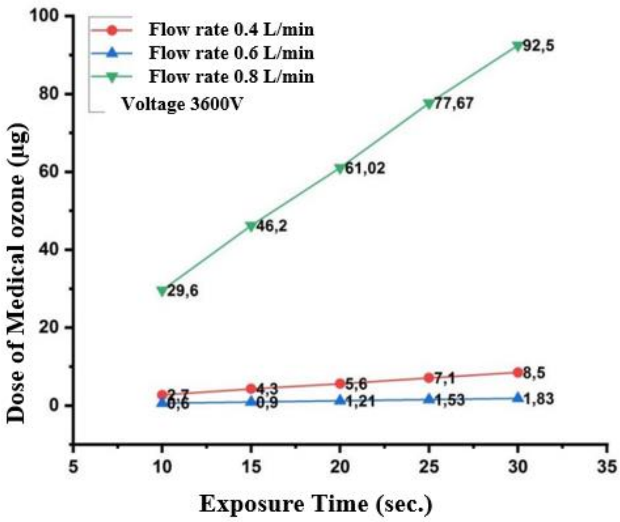

Fig. 9 Dose as a function of time at a voltage of 3600 V in a DDBD reactor with a frequency of 70 Hz.

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This ozone generating machine must produce pure O_2 and O_3 without being contaminated by other elements.The homogeneity of the oxygen-ozone mixture can only be achieved if MOG uses oxygen at medical oxygen standards with a minimum purity of 99.5%. The concentration expressed in µg/mL must have a margin of error equal or better than ±10%. No other substances besides O_2 and O_3 may be present in the produced gas mixture [12]. Figure 9 shows a graph of the dose relationship as a function of exposure time at a voltage of 3600 V for all variations in flow rate. This dose comes from the concentration produced by the ozone which is still very small. Does not meet standards for MaH.

Table 2. Summary of the results of this research regarding medical ozone generators

The precise ozone concentration produced by MOG is (1 µg/mL - 80 µg/mL)				
Source gas	Pulse Frequency	Flow rate	Operation Voltage	Concentration
uses oxygen at medical oxygen 99.5 %	60 Hz	0.2 L/min - 0.6 L/min	3000 V	20 µg/mL -70 µg/mL
	60 Hz	0.2 L/min	3000 V - 3300 V	20 µg/mL - 40 µg/mL

5. Conclusion

Medical ozone generator (MOG) which uses International Scientific Committee of Ozone Therapy standards, the Medical Ozone Generator (MOG) can be produced using the DDBD rector. MOG has been realized with operational settings using a touch screen. Modifications need to be carried out because the combination of operational voltage, pulse frequency and oxygen flow rate still needs to be optimized.

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