Electrical Study of DDBD Reactor with Mesh-Mesh Electrodes as a Medical Ozone Generator to Produce Standard Doses for Major Autohemotherapy in Small Animals

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Abstract:- Medical ozone can be produced using a Double Dielectric Barrier Discharge (DDBD) plasma reactor. This research aims to obtain a medical ozone dose that meets the Madrid declaration standards, for major ozone autohemotherapy. This reactor uses a mesh-mesh electrode configuration made from aluminum. High pulsed AC voltage is applied in the range of 500 V to 3900 V, Frequency 60 Hz, and Flow rate variation from 0.2 L/min to 0.8 L/min. The results of the research show that the higher the voltage, the higher the current produced so that the ozone concentration obtained is also higher with several variations in flow rate, and the ozone dose obtained and in accordance with the ozone dose range based on the Madrid Declaration for small animals with ozone major autohemotherapy in the category low and medium doses.

***Keywords:-** Double Dielectric Barrier Discharge, Medical Ozone, Major Autohemotherapy, Low and Medium Doses.*

I. INTRODUCTION

Ozone (O_3) is a naturally occurring component of fresh air, formed as a result of the reaction between ultraviolet rays from the sun and the upper layer of the earth's atmosphere, and forms a protective layer that covers the earth [1]. Ozone can be produced from an electrical discharge when an electrical discharge (spark) splits oxygen molecules into two oxygen atoms and then reacts with oxygen molecules to form ozone [2], using UV radiation, Corona Discharges, or Dielectric Barrier Discharges (DBD) [3,4]. Ozone has many benefits, one of which is in the medical field. The success of using ozone in the medical world has proven its validity from several previous studies, including that medical ozone has been widely used in treating disease, because medical ozone has the ability to kill bacteria, viruses and fungi, improve tissue circulation, accelerate tissue epithelialization and stimulate cell regeneration [5] use of ozone as a therapeutic agent for various disorders [6]. Ozone therapy has the power to stimulate antioxidant responses in cardiomyopathy patients [7] and improve hemoglobin oxygenation in diabetes patients [8]. Ozone also provides a protective effect against liver damage caused by carbon terachloride and renal ischemicreperfusion due to its stimulating oxidative preconditioning mechanism. endogenous antioxidant system and modulates nitric oxide (NO) [9]. Ozone therapy is also able to increase oxidative stress and the antioxidant system so it is considered as an adjuvant to insulin in the treatment of Diabetes Mellitus to prevent and relieve nephropathy that occurs due to Diabetes Mellitus [10]. Ozone used in the medical world is different from ozone for industry. Ozone gas used for industry uses free air as its oxygen source, while for medical purposes it uses pure oxygen [11]. Medical ozone can be obtained from the DDBD reactor because this reactor is considered to be more qualified as a medical reactor because there is a space between two barriers which functions as a place for pure oxygen to flow and when it reacts with an electric field, high purity ozone is produced [12].

Medical ozone can be applied to veterinary medicine, one of which is the MAH method. This is one of the most frequently used forms of application in ozone therapy [13]. Major autohemotherapy (MAH) is a method of administering ozone therapy which consists of taking the patient's venous blood, mixing it with oxygen/ozone, and reintroducing it into the body through a vein [14].

Based on the background description above, this research will observe the ozone concentration produced from the DDBD reactor with several oxygen flow rates at certain voltages to obtain a medical ozone dose that meets the Madrid Declaration standards for major autohemotherapy ozone therapy for ozone therapy in small animals.

II. RESEARCH METHODS

This research uses a DDBD reactor with a cylindrical geometry with a mesh electrode configuration made from aluminum plates as in Figure 1. The reactor is made of a barrier in the form of a borosilicate glass (pyrex) tube with a length of 19 cm and a thickness of 0.2 cm. The outer diameter of the tube is 4 cm and the inner diameter is 2 cm. The electrodes used are aluminum mesh sheets arranged in a cylindrical shape with a length of 15 cm and a width of 15.5 cm for the outer electrode, while for the inner electrode it is 15 cm long and 9 cm wide. The inner and outer electrodes are connected to a pulsed AC voltage source with a voltage variation of 500 V – 3900 V and a frequency of 70 Hz. The electrode is also connected to a high voltage probe to convert the high voltage to one per thousand so that it can be read on a voltmeter and connected to an ammeter to determine the value of the current produced. At both ends of the reactor, holes face upwards for gas input and output. The inlet gas port is connected with a hose to the oxygen cylinder, while the outlet is connected with a PU (Polyurethane) material hose to the ozone monitor so that the resulting ozone concentration can be read. The input gas is oxygen with a flow rate of 0.2 L/min – 0.8 L/min. When ozone has been produced, the ozone capacity is calculated to determine the ozone dose for MAH and adjusted to the rules of the Madrid Declaration on Ozone Therapy 2020 [13], in order to find the appropriate dose of medical ozone for major autohemotherapy therapy for the treatment of small animals such as in table 1.

Table 1 Application of Medical Ozone in Small Animal Treatment by Methods *Major Autohemotherapy*

Method	**O_3**	**Doses**		
		high	**Medium**	**Low**
Major Autohemotherapy	V(mL/Kg)	1-1.5	1-1.5	1-1.5
	Doses(μg/Kg)	30-35	20-30	10-20

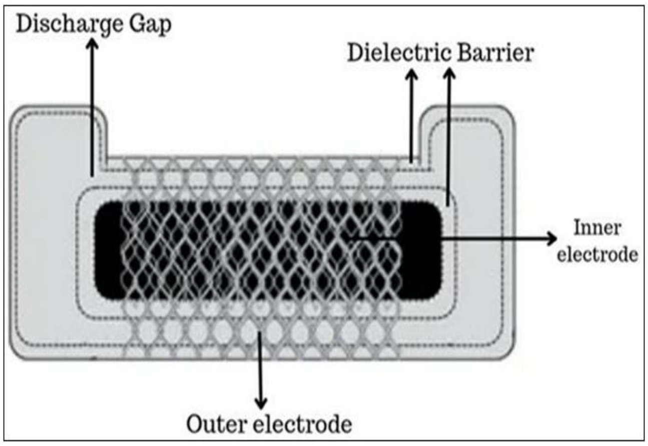

Fig 1 DDBD Reactor Schematic using Aluminum Mesh Electrodes

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

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

Where Cp_{O_3} is the ozone capacity, namely the level of ozone that is able to flow into the solution with the units used being grams/hour or micrograms/minute and flowrate is the ozone flow rate, the units used are L/hour. Meanwhile, the ozone dose can be calculated using the formula [16]:

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

Where Cp_{O_3} is the ozone capacity whose units are grams/hour or micrograms/minute and expose t_{expose} is the ozone exposure time whose units are minutes. Experimental set up medical ozone generator circuit schematic can be found in the figure 2.

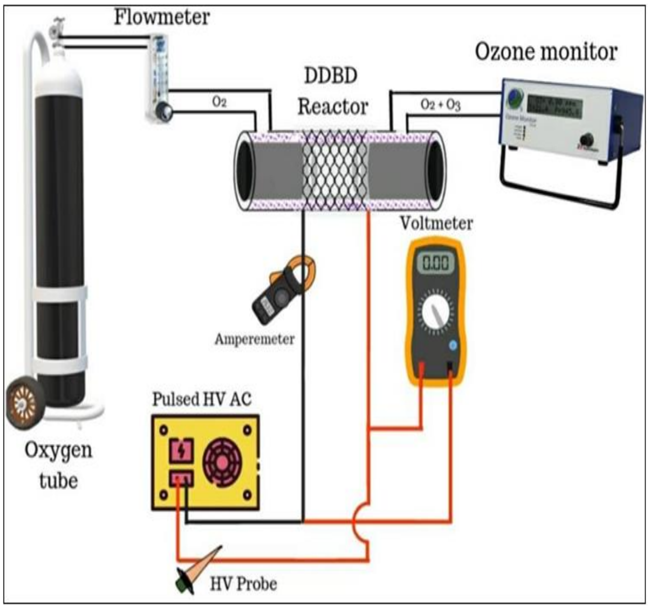

Fig.2.Experimental Set Up Medical Ozone Generator Circuit Schematic

III. RESULT AND DISCUSION

A. *Characteristics of Current as a Function of Voltage*

This research uses a DDBD reactor with voltage variations from 500 V – 3900 V at a frequency of 70 Hz and the oxygen flow rate used is 0.2 L/min – 0.8 L/min. The current value as a function of voltage can be seen in Figure 2. This figure shows a graph of the increase in electric current due to increased voltage. This happens because a higher voltage results in the creation of a greater potential difference between the electrodes and then creates a stronger electric field [17]. The electric field then accelerates the movement of particles, ions and electrons so that collisions occur and trigger the processes of ionization, excitation, dexcitation and recombination and produce an electric charge [18]. I-V characterization can use the Robinson formula for the relationship between current and voltage which has been modified by Nur *et al.* 2017 [19]. Robinson's formulation in 1961 was theoretically expressed in the following equation (3) [20]:

$$I_S = \frac{2\,\mu_0\,\varepsilon_0}{d}(V - V_i)^2 \tag{3}$$

Where I_s is the saturation current (mA), μ_0 is the average charge mobility (cm^2/volt.sec), ε_0 is the permittivity, V is the operating voltage, and V_i is the corona threshold voltage in volts. Robinson's formula is modified by including the electrode area and medium between the two electrodes. This modification allows formula I(V) from Robinson's formulation to be used in a reactor that has an electrode area and a medium between two electrodes consisting of gas and glass.

The current and voltage characteristics after modification are as follows [19]:

$$I_S = \frac{2\,\mu_{RT}\varepsilon_t\,S}{d^3}(V - V_i)^2 \tag{4}$$

Where S is the surface area of the passive electrode (cm^2) and d is the distance between electrodes (cm), ε_t is effective permittivity and μ_{RT} is the mobility of electric charge carriers.

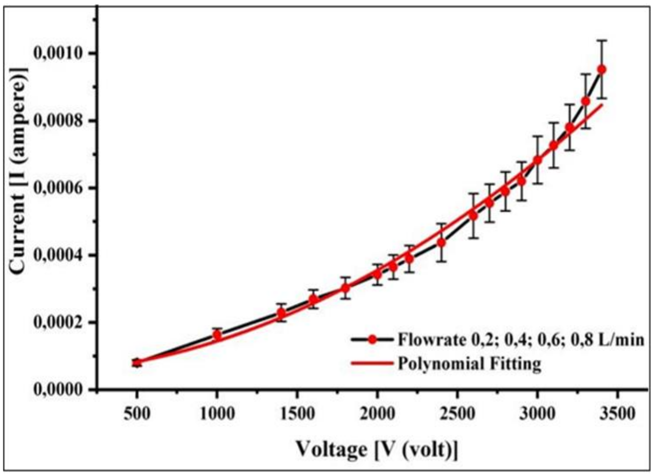

Fig 3 Current characteristics as a function of voltage in the DDBD Reactor for Several Flowrates

From figure 3 data obtained based on this experiment and fitting the data shown in this figure, the scond order polynomial equation is obtained as I = $5.2\text{x}10^{-5} + 3.4\text{x}10^{-8}$ V + $5.9\text{x}10^{-11}$ V^2. The results of this data fitting show that it is in accordance with the formulation carried out by Nur *et. al.* [19]

B. *Effect of Voltage on Input Power*

Variations in the voltage provided can affect the value of the input power produced as shown in Figure 4. The input power produced is 0.04 watts – 3.24 watts. The greater the voltage, the greater the input power. This trend applies to all oxygen flow rates 0.2 L/min – 0.8 L/min.

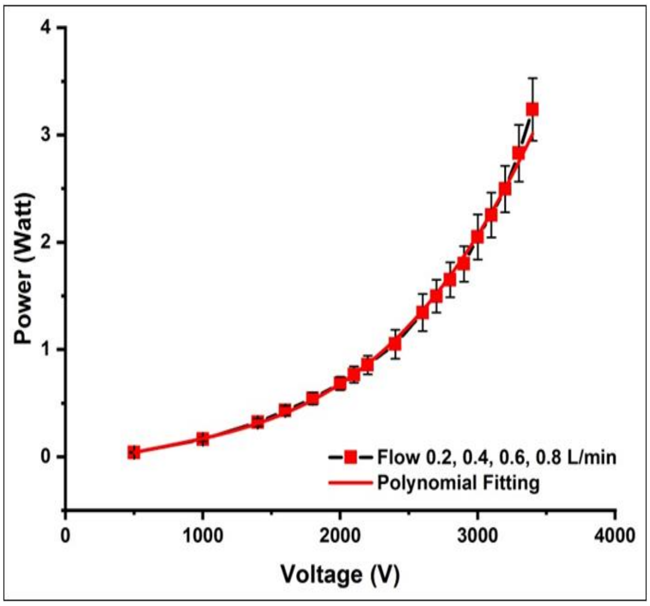

Fig 4 Input Power Value as a Function of Voltage

Input power (P) can be determined based on current and voltage measurements or I-V characteristics, besides that it can also be determined by multiplying the voltage (V) by the current (I) using the equation below:

$$P = I\,V \tag{5}$$

Equation (4) if inserted into equation (5) input power based on the modified Robinson formulation, can be obtained the theoretical equation for input power [19]:

$$P = \frac{2\,\mu_{RT}\varepsilon_t\,S}{d^3}(V - V_i)^3 \tag{6}$$

From the equation above it can be said that the input power is proportional to the power of 3 ($P \approx V^3$). From the data obtained based on this experiment and fitting the data shown in Figure 4, the third order polynomial equation is obtained as follows. P = $1.2\text{x}10^{-1} + 4.0\text{x}10^{-4}$ V – $2.2\text{x}10^{-7}$ V^2 + $1.1\text{x}10^{-10}$ V^3. This shows that the Robinson formula [20] is not only valid for corona discharge but can also be used for double dielectric barrier discharge according to the modification carried out by Nur *et. al.* [19].

C. *Influence of Voltage on Ozone Concentration and Capacity*

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 influence ozone production, where the higher the voltage applied, the greater the potential difference between the electrodes. The greater the potential difference causes the more charged particles to have sufficient energy to ionize or excite oxygen molecules when a collision occurs. The collision results in the formation of more ozone [21]. This research is in accordance with that carried out by Rahardian et al. 2020 [22] and Restiwijaya et al 2019 [23]. This research is also in accordance with research conducted by Garamoon et al. 2009 [24]; Nur et al. 2019 [25], which shows that the higher the voltage, the higher the resulting concentration.

The process of ozone formation occurs when high voltage is applied to the reactor so that electrons will experience accelerated collisions with oxygen atoms in the reactor [26, 27]. The collision occurs in the space between the two electrodes, which is a narrow gap for ozone formation in the reactor. This gap is limited by a dielectric barrier in the form of pyrex, so it can prevent arc discharges. Dielectrics can weaken the electric field between the two electrodes because there is an electric field from the molecules in the dielectric whose direction is opposite to the electric field of the potential difference. The process of ozone formation is when the reactor provides high voltage, the initial electrons will be accelerated and collide with oxygen atoms in the reactor. These collisions result in a doubling of electron folds and produce ions and free radicals. The ions that may be formed are O+, O+, O-, O2-, and O-. Meanwhile, the radicals that may be formed are O* and O*. These ions and radicals are very reactive so they react with each other and produce a new species, namely O3. The formation of O3 or ozone begins with dissociation (3), dissociative binding (4) and dissociative ionization (5) as follows [28]:

Dissociation $$e^- + O_2 \rightarrow 2O + e^- \quad (3)$$

Dissociative binding $$e^- + O_2 \rightarrow O + O^- \quad (4)$$

Dissociative ionization $$e^- + O_2 \rightarrow O + O + 2e^- \quad (5)$$

Then the oxygen radicals will react with oxygen to produce ozone (7) with the help of neutral molecules as a catalyst. as follows

$$O_2 + e \rightarrow 2O + e \quad (6)$$

$$O + O_2 + M \rightarrow O^3 + M \quad (7)$$

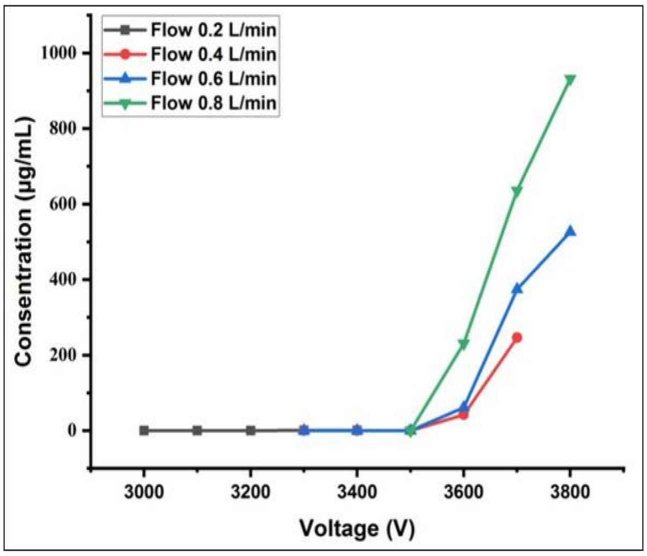

Fig 5 Ozone Concentration as a Function of Voltage

Ozone is formed at a voltage of 3600 V to 3800 V. Figure 5 shows that the ozone concentration increases with increasing voltage applied at both oxygen flow rates of 0.2 L/min to 0.8 L/min with intervals of 0.2 L/min. At high flow rates, the voltage experiences saturation more quickly than at low flow rates. In other words, at high flow rates damage occurs more quickly than at low flow rates. The ozone concentration value detected on the ozone monitor is one of the determinants of the capacity value besides the oxygen flow rate. Ozone capacity is related to the amount of ozone formed in a certain time. Apart from that, capacity is also an important parameter in calculating ozone dose. Ozone capacity can be calculated using equation (1). The effect of voltage on ozone capacity at several flow rates can be seen in Figure 6.

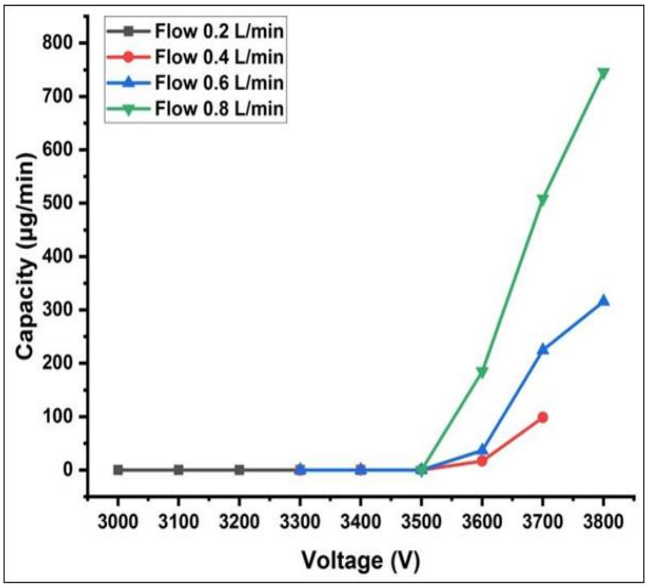

Fig 6 Ozone Capacity as a Function of Voltage

D. The insfluence of flowrate on concentration

The effect of flow rate on ozone concentration at several voltages can be seen in Figure 7.

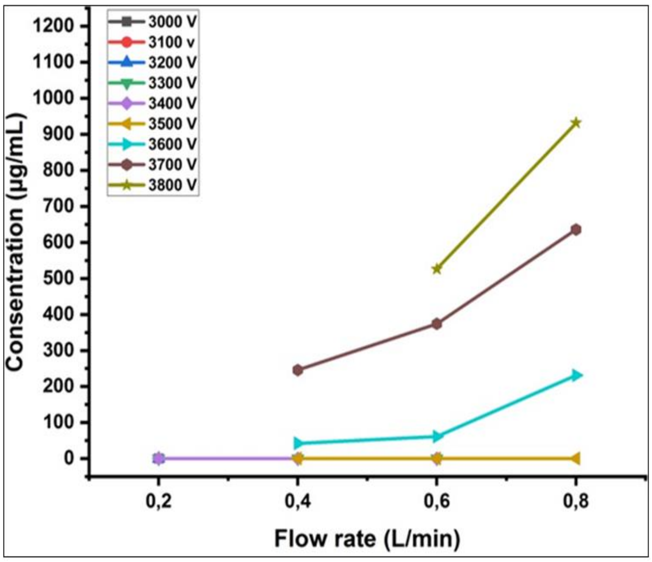

Fig 7 Ozone concentration as a function of flowrate

E. The influence Effect of flowrate on ozone capacity

The effect of voltage on ozone capacity at several flow rates can be seen in Figure 8. Ozone capacity is an important parameter in calculating ozone dose.

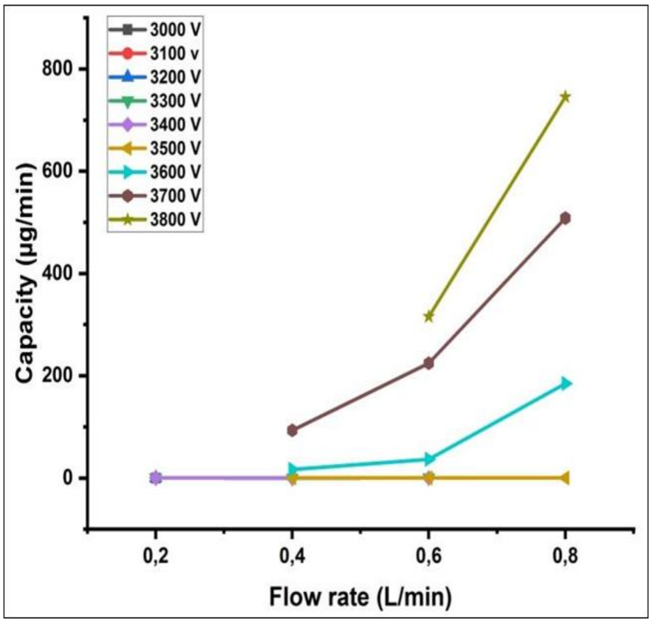

Fig 8 Ozone Capacity as a Function of Flowrate

F. Obtaining Dosage for Medical Ozone

The ozone dose can be determined by multiplying the ozone capacity by the reactor operating time. The longer the ozone flow time, the greater the dose produced. The effect of medical ozone dosage on time depends on the context of use and is also related to possible side effects. 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 administering medical ozone doses to small animals using the major autohemotherapy method as stated in the Madrid declaration which can be seen in table 1.

The ozone dose obtained from the DDBD reactor with various flowrate variations at certain voltages with various time variations can be seen in Figure 9 below.

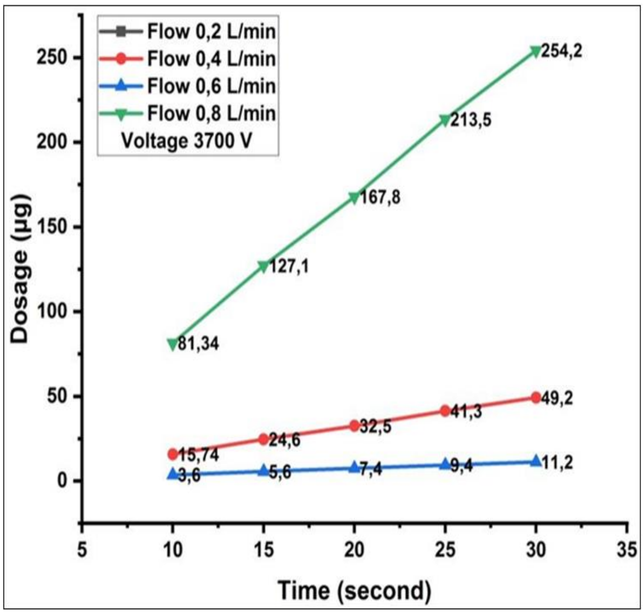

Fig 9 Doses as a Function of Time at a Voltage of 3700 V, for Several Flowrate.

Figure 8 shows a graph of the dose relationship as a function of time at a voltage of 3700 V for all variations in flow rate. In the figure, the highest dose value is shown at flow 0.8 L/min, namely 81.34 µg to 254.2 µg, while flow 0.4, namely 15.74 µg to 49.2 µg, and the lowest dose value is at flow 0.6 L/min i.e. 3.6 µg to 11.2 µg. For a flow of 0.2 L/min at a voltage of 3700 V, no ozone formation was detected. The data presented in Figure 9 for all dose values produced at a voltage of 3600 V in the DDBD reactor with mesh shows that there are two dose values that correspond to the major dose range of autohemotherapy for small animals, namely 11.2 µg.

With an exposure time of 30 seconds and a flow rate of 0.6 L/min; and 15.74 µg with an exposure time of 10 seconds and a flow rate of 0.4 L/min. Both doses are included in the low dose category

IV. CONCLUSIONS

DDBD reactors with cylindrical cylinder configurations with mesh electrodes can be used to produce medical ozone. The higher the voltage, the higher the ozone concentration produced. This generator has been able to achieve ozone doses that comply with the ozone dose range based on the Madrid Declaration for small animals with major autohemotherapy ozone therapy. Therefore, the reactor used in this research is suitable as a reactor producing standard medical ozone doses according to the Madrid Declaration for therapeutic treatment of small animals in a major way autohemotherapy. Apart from that, electrical studies have shown that the electric current in the DDBD reactor is proportional to the power of two of the voltage, while the power is proportional to the power of three of the voltage. These findings add to the evidence that the modified Robinson formulation [19] also applies to DDBD

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