Analysis of Ozone Generated in an Atmospheric Pressure Co-axial Dielectric Barrier Discharge (APDBD)

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Abstract : In this paper, a coaxial Dielectric Barrier Discharge (DBD) reactor operating at atmospheric pressure used for the production of ozone is presented. The gas flow rate was varied from 4.5 l/min to 15.5 l/min has been measured by an indigenously designed system based on Venturimeter. The effect of applied voltage (6.50- 8.31 kV) on the ozone concentration with the constant flow of air has been investigated. The variation of ozone with the time and flow of air is observed at a constant voltage. It is found that the concentration of ozone increases with increasing discharge voltage and decreases with increasing flow rate after attaining optimum value for a typical device. The power used for the device at applied voltage 8.31 kV was found to be 292W by using TC Manley's equation

***IndexTerms* - APDBD, Electrical characterization, Ozone concentration measurement, Power measurement.**

INTRODUCTION

Dielectric barrier discharges have been known for more than a century before which were reported by Von Siemens for first experimental purpose in 1857[1]. They concentrated on the generation of ozone by supplying a flow of oxygen or air to the influence of dielectric-barrier discharge (DBD) maintained in a narrow annular gap between two co-axial glass tubes by an alternating electric field of sufficient amplitude. The main role to identify the characterization of discharge was made by the electrical engineer K. Buss, who found out that breakdown of atmospheric-pressure air between planar parallel electrodes covered by dielectrics always occurs in a large number of tiny short-lived current filaments [1, 2]. Due to the presence of the current filament oxygen molecules breakdown and form nascent oxygen which then combine with oxygen molecules and form ozone molecules [3].

Thus formed ozone (O_3) is highly reactive chemical with a high oxidation potential of 2.07 V [4-5] which were widely used in industrial application including bacteria, algae, spores killing and vanishing volatile organic compounds, odor treatment, enhancing fertilization, purification of ambient air and potable water, disinfecting food products to increase shelf life; fumigation of operation theaters in hospitals, sterilization of operational tools and personnel. The source of ozone for the practical applications is typically used in electrical discharge primarily; Corona discharge [6] and Dielectric barrier discharge [7-9]. In DBD, ozone is produced at room temperature and pressure with air or oxygen preceding in two main processes of dissociation and formation [10, 11]. Initially, an oxygen atom is dissociated by collision with high energy electrons and oxygen molecules illustrated in equation 1 and thus obtained nascent oxygen combine with free molecules O_2 and form O_3 as expressed in equation 2.

$$e + O_2 \longrightarrow O + O + e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$2O_2 + O \longrightarrow O_3 + O_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Among many applications of ozone, treatment of waste water is the very important one. The main reason for using ozone for this purpose is that it does not leave the rest of the reaction in the water because the ozone dissolve thirteen times more easily than the oxygen [12, 13].

In this paper, the fabrication of multiple tube DBD system has been used for the investigation of concentration of ozone with varying voltage and a constant flow of air is adjusted by using dimmer on a commercially designed blower system measured by indigenously fabricated Venturimeter.

EXPERIMENTAL SETUP

The scheme of ozone generating system by using dielectric barrier discharge that was designed can be shown in fig.1. The ozone generator consists of tube made of borosilicate glass with length 49.5 cm; inner and outer diameter are 2.4 cm and 2.6 cm respectively. The ozone generator was connected to the high voltage power supply by two electrodes, the anode was connected through copper rod of length 54.5 cm, adjusted inside the tube with the help of cork (Teflon), and the cathode was connected by sheet of aluminum foil of thickness 0.5 mm and length 29.8 cm wrapped outside of the tube. The discharge gap between the inner electrode and barrier (borosilicate tube) was 4.0 mm. The tube have two open end, one to inlet gas and other to outlet the ozone.

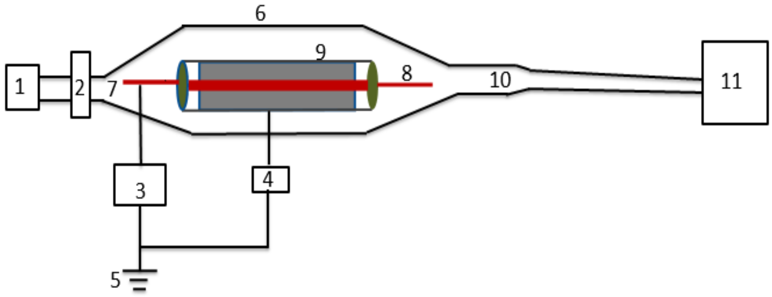
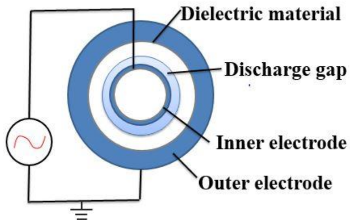


Fig.1: Photograph and Schematic diagram of co-axial dielectric barrier discharge; 1-air blower, 2-Venturimeter, 3-High voltage power supply, 4-10K/10W resistor, 5-ground, 6-Reactor, 7-air inlet, 8-Inner electrode (copper rod), 9-Outer electrode (aluminum foil), 10-Ozone outlet, 11-Ozone analyzer

The reactor, whose length was 133.5 cm, and distance from the output of the reactor to ozone analyzer was 106.5 cm. The high voltage AC transformer (0-18kV, 50 Hz, NEEK) was used to supply high voltage to the ozone chamber having 14 identical DBD tube. The gas flow was monitored by the indigenously designed venturimeter with the help of dimmer fitted on air blower (ALPHA, A4285, 0-50Hz, 450W, 25m^3/min), and the ozone concentration was measured by ozone analyzer (Ozone Analyzer BMT 964). To study the effect on ozone concentration, different voltages and varying gas flow rate were used. The applied voltage and the discharge was measured by using 10:1 voltage probe (Tektronix 2000 TDS) and discharge current was measured by current probe. In this experiment digital oscilloscope was used to obtain voltage and current wave form.

(a)

(b)



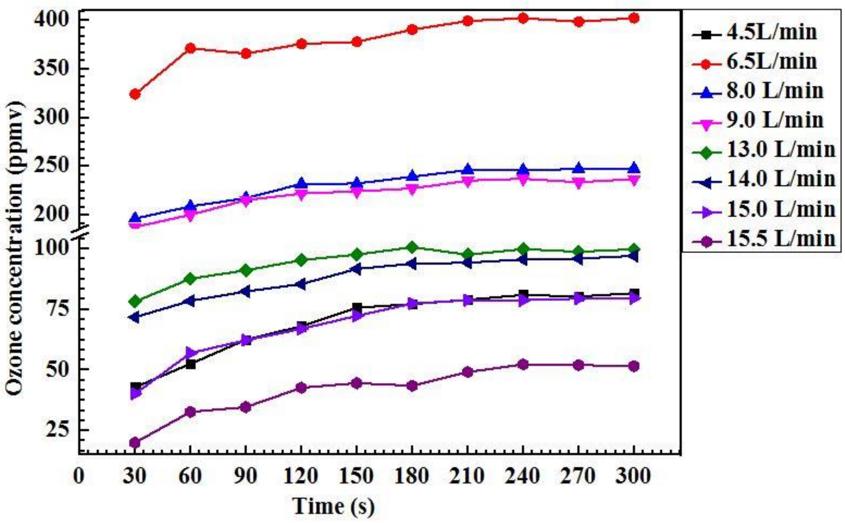
(c)

Fig.2: Photograph of (a) air pump which is adjusted by the dimmer to control the air flow rate. (b) The venturimeter which is used to measure the air flow rate. The maximum flow rate that can be measured by this set up is 15.5 l/min. (c) Dielectric barrier discharge

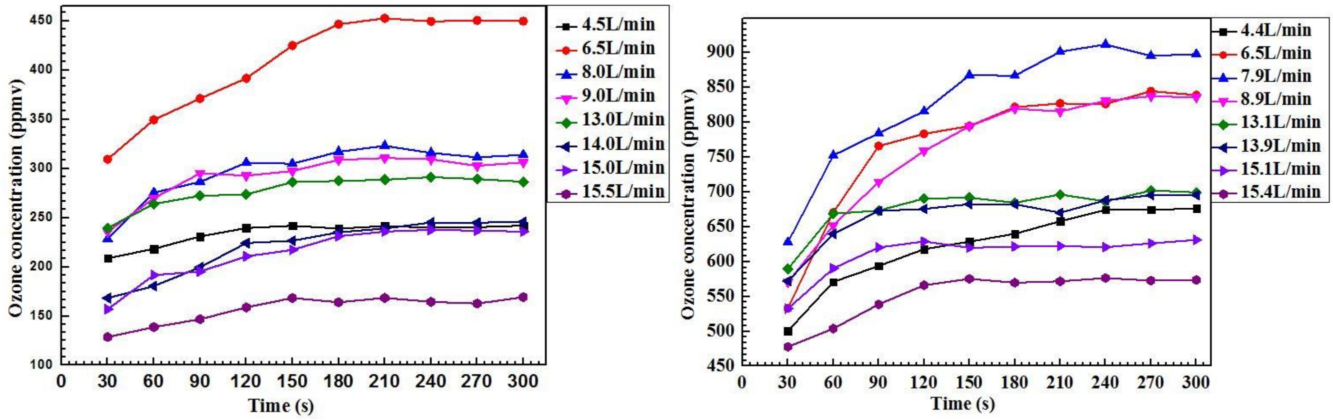
RESULTS AND DISCUSSION

Effect of Time on Ozone Concentration

Figure 3(a) shows the variation of ozone concentration as a function of time for a constant flow rate at a particular voltage. To study the saturation time experiment was repeated and it is evident that ozone increases as time increases and becomes saturated after some time. It is due to the reason that as the time increases the oxygen molecules collides with the electrons, reducing the number of excited species, which influence the rate of plasma chemical reaction and it takes some time to build step ionization phenomenon which is responsible to yield more amount of ozone. Similar trend is followed for figure 3(b) and 3 (c).



(a)



(b) (c)

Fig. 3 : Ozone concentration as a function of discharge time at applied voltage (a) 6.50 kV (b) 7.80 kV (c)8.31 kV.

Effect of Gas Flow Rate on Ozone Concentration

The effect of air flow rate on ozone concentration is shown in fig.4. Results show that there exists an optimum flow rate at which the concentration of ozone becomes maximum. This is due to the dependence of ozone concentration on number of oxygen molecules/volume and its residence time inside the discharge tube. At higher flow rate, the residence time of the gas inside the discharge tube diminishes and hence the probability of collision of oxygen molecules with electron decreases. Therefore, it reduces the rate of ozone formation.

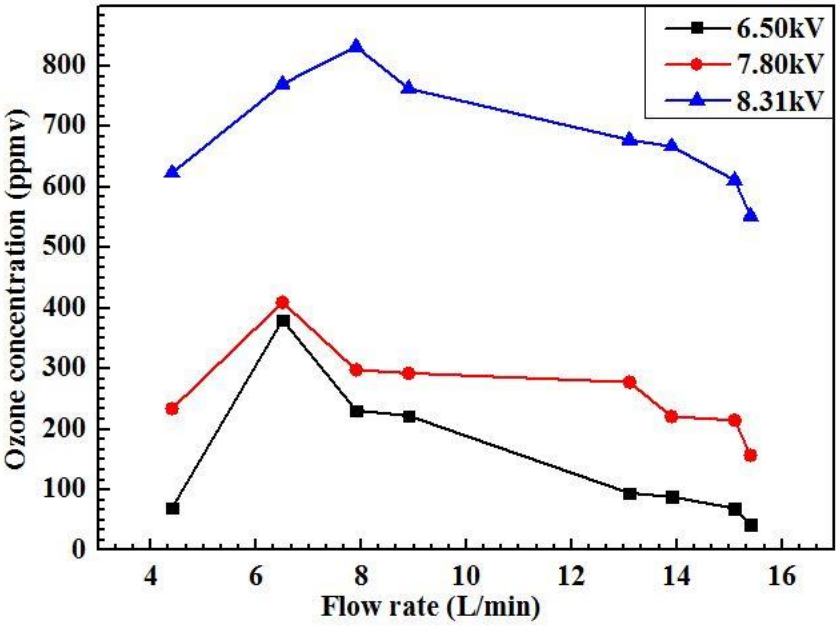


Fig.4: Ozone concentration as a function of flow rate at constant applied voltage

Effect of Voltage on Ozone Concentration

Figure 5 shows the effect of applied voltage on ozone concentration which illustrates that there exist an increase in ozone concentration while increasing the applied voltage. But, due to the limitation of this device, it is unable to study on the higher voltage. Some research paper shows that ozone concentration increase up to certain voltage and decreases while further increasing the voltage [8,10]. It is due to the fact that the increase in voltage increases with the electrical energy density which means more energy transferred to the electrons inside the discharge tube increases the probability of collision of oxygen molecules with electrons. However, supplied energy may not always be sufficient for the recombination of gaseous species (as ions, radicals etc.) which are important for ozone generation inside the ozone reactor or DBD system. This result is in good agreement with results published in articles [14].

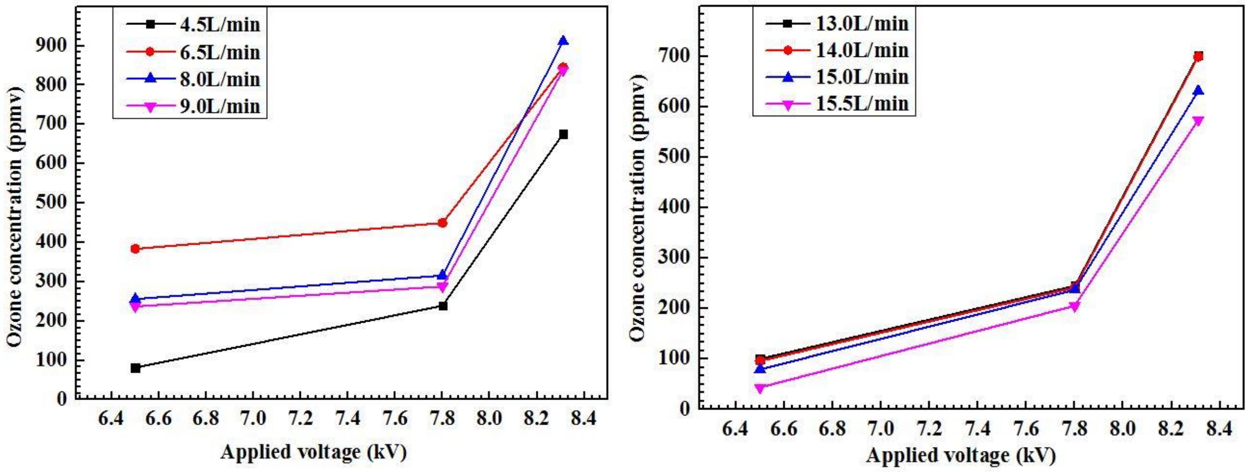


Fig.5: Ozone concentration as a function of applied voltage at constant flow rate.

Measurement of Power Consumed by DBD

The measurement of the plasma power consumption is essential for all the dielectric barrier discharge in order to determine the plasma produced in number of application. The calculation of power consumed in DBD plays the key role in number of application. The concern of this experiment is to calculate the power consumed during ozone generation. The characteristics I-V curve with applied voltage 8.31kV is shown in the Fig.6.

The varieties of method are invoked in calculation of power. In this experiment T.C Manley equation is exploit to calculate the power [15].

$P_{elec}=4V_0C_df_{ac}(C_d/(C_d+C_g))(V_m-V_o)$

The main plasma device parameter including C_d, C_g and C_{tot} can be obtained from the Lissajous curve. A graphical overview of Lissajous curve is shown in the Fig.7.

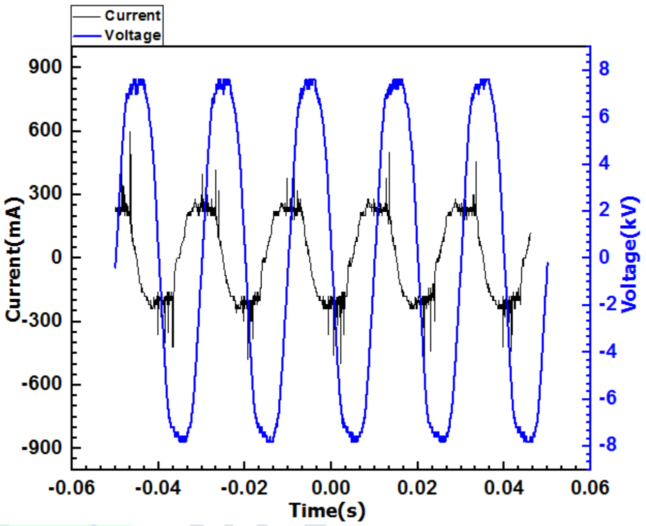


Fig. 6: Characteristic of I-V curve at applied voltage 8.31kV

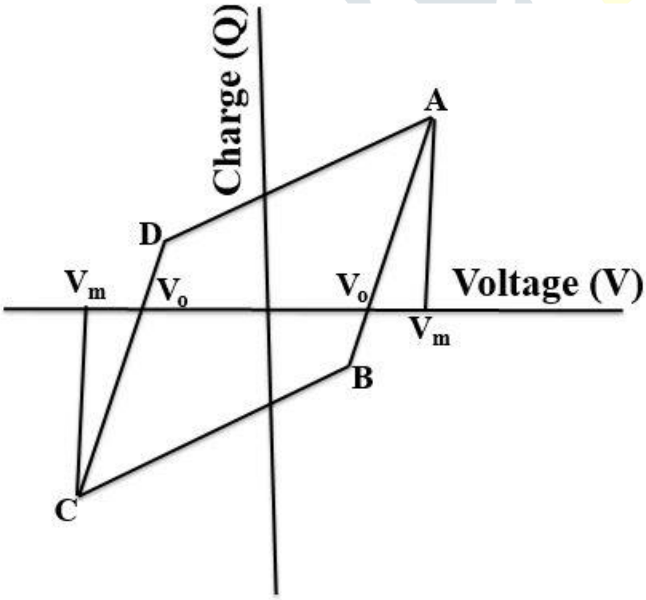


Fig.7: Schematic representation of voltage/charge Lissajous.

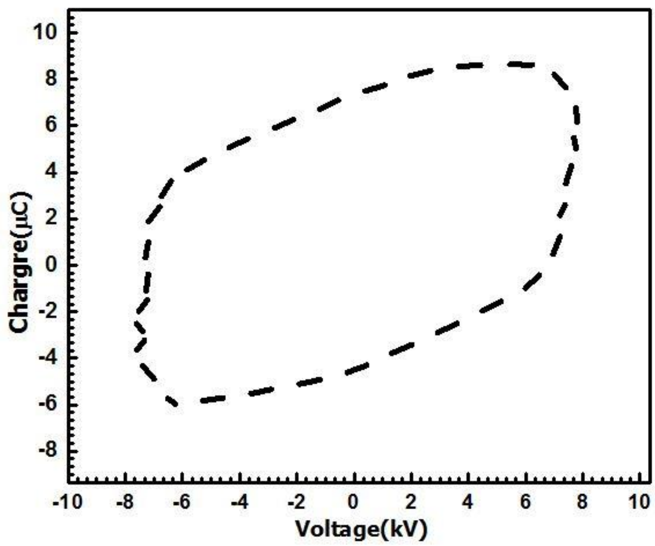


Fig.8: Lissajous figure for the voltage 8.31 kV.

The AD and BC sides of the parallelogram correspond to "the passive or dark phase of the" DBD [16]. During this phase, no charge transfer through the gas gap is observed and the slope of these two sides is equal to the total capacitance (C_{total}), which can be calculated as a series connection of gas gap capacitance (C_g) and dielectric barrier capacitance (C_d) given by equation $C_{total} = C_gC_d/(Cg + C_d)$

The DC and AB sides of the parallelogram are related to "the active phase", where the slope is equal to the dielectric barrier capacitance (C_d).The calculation of power consumed by the DBD is found to be 292.0Watt for maximum ozone concentration.

CONCLUSION

Using a dielectric barrier discharge quantitative measures of ozone generation has been done. Influence of the discharge conditions such as by supplying air at atmospheric pressure, different time, different flow rate and different voltage on the yield of ozone has been investigated. It was found that saturation time of ozone concentration of typical device is almost 210 s. Also the effect of varying flow rate on ozone concentration was analyzed which conclude that, ozone concentration increases for certain flow rate attaining maximum concentration than decreases with increasing flow rate. Further, in case of applied voltage, as the applied voltage increases ozone concentration increases. It is obtained that power used in this device to obtain maximum ozone concentration is 292.0 W calculated from TC Manley equation.

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