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Experimental Study of Ozone Generation by Atmospheric Pressure Dielectric Barrier Discharge

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***Abstract*: Ozone is well known as the most useful oxidant for wide industrial application due to its strong oxidizing power and non formation of undesirable by-product. This paper reports an ozone generator which has been designed according to dielectric barrier discharge (DBD) technique with oxygen and air as working gas. Ozone was generated by applying voltage in the range of (0-18) *kV* with frequency 50 *Hz*. The main objective of this work is to investigate the effect of the gas flow rate, applied voltage and geometry of the electrode on the rate of production of ozone. In this experiment, the gas flow rate was varied from 0.25 *l/min* to 4 *l/ min* for three different length of electrodes namely; 15 *cm* and 23 *cm* and 31 *cm*. A maximum ozone concentration of 3700 *ppmv* was obtained with the applied voltage of 10kV and oxygen flow rate of 0.25 *l/min*. It was found that ozone concentration increases with increase in applied voltage and decreases with increasing flow rate for fixed applied voltage. For fixed applied voltage, ozone concentration is maximum in case of electrode length 23cm.**

Key words: Ozone, Dielectric barrier discharge.

I. INTRODUCTION

Ozone (O_3) is a highly reactive chemical with a high oxidation potential of 2.07 V [1-2]. It has been successfully used in wide 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. It has definite advantages over other commercial oxidants, namely no undesirable by product or residues are formed. The most important reason for using ozone for water treatment is that it can destroy organic compounds and can kill bacteria [3-6]. Due to its attractive properties several methods of enhancing the production rate of ozone have been investigated. Most widely used methods for ozone generation are: ultraviolet radiation, electrolysis, radiochemical, corona discharge and dielectric barrier discharge. Any method of generating ozone relies on applied energy to break the bonds holding the oxygen atoms in a molecular form allowing them to dissociate and then reform as ozone.

The source of ozone for practical applications is typically used in electrical discharge primarily; corona discharge [7] and dielectric barrier discharge [8-10]. In DBD, ozone is produced at room temperature and pressure with air/oxygen assisting in two main processes of dissociation and formation [11]. Initially, an oxygen atom is dissociated in collisions between high energy electrons and oxygen molecules described by Eq. (1) Alongside the radicals combine with free molecules O_2 and form O_3 as expressed by Eq. (2). These processes are described conceptualized in Figure 1.

$$e + O_2 \rightarrow O + O + e \text{-----------} (1)$$
$$2O_2 + O \rightleftharpoons O_3 + O_2 \text{-----------} (2)$$

The processes are reversible and have half-lives of only tens of minutes at the ambient temperature.

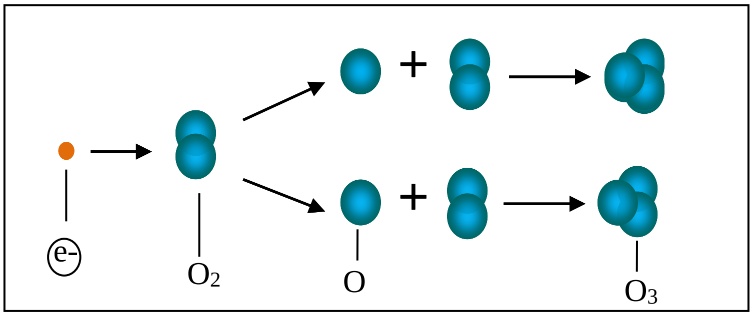

Fig. 1 Schematic diagram of formation of ozone by electron impact.

One of the very important applications of ozone is in treatment of waste water. 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 decomposes back into oxygen. Another reason is the ability of ozone to dissolve in water thirteen times more easily than oxygen [12, 13]. With more application and increasing consumption, improvement in production efficiency is required.

In this paper, production of ozone by dielectric barrier discharge has been presented. An attempt has been made to find out the optimum condition for higher ozone yield in annular reactor

II.EXPERIMENTAL SETUP

The schematic diagram of ozone generating system is shown in Fig. 2. AC high voltage was applied to a co-axial electrode arrangement by a step up transformer (0-18) kV with frequency 50Hz. The central electrode was made of a brass rod fixed inside a glass tube of thickness 1mm. The gap between two glass layers was 2mm. A sheet of aluminum wrapped outside of the tube acted as the outer electrode. In this system, air and oxygen were used as the working gas. The gas passes inside the tube through the gap between the two glasses.

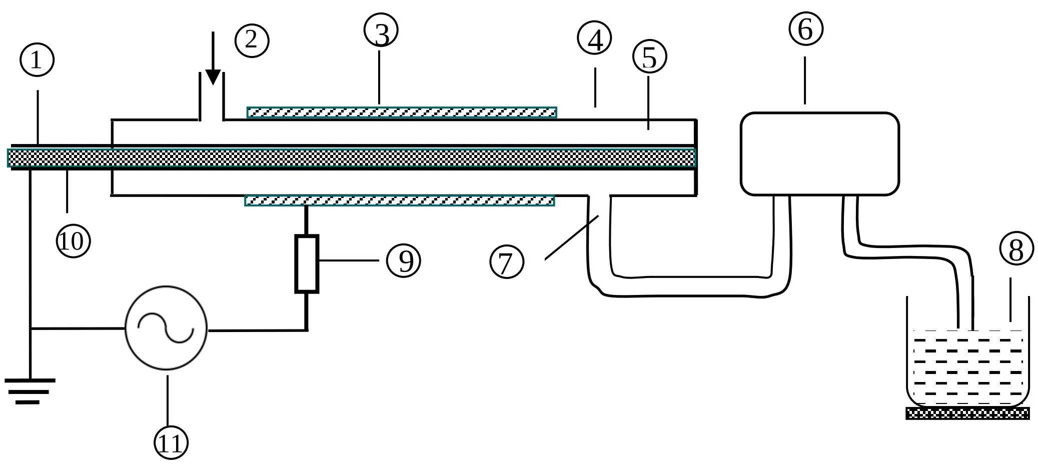

Fig.2: Schematic diagram of ozonizer, 1-Dielectric material , 2-Gas inlet, 3- Aluminum Sheet, 4-Glass tube, 5- Gap, 6-Ozone Analyzer, 7-Out let (mixture of air and ozone), 8-Beaker with water, 9-Resistance 10 kΩ, 10- Central electrode, 11-Power supply (18 kV, 50 Hz)

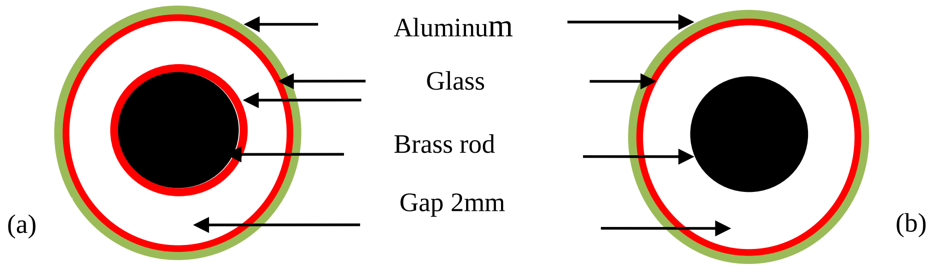

Fig.3: Cross sectional view of ozone generator with double barrier (a) and single barrier (b), Diameter of brass rod = 8mm, Thickness of dielectric (glass) = 1mm, Internal Diameter of glass = 10mm, Thickness of aluminum sheet = 0.5mm

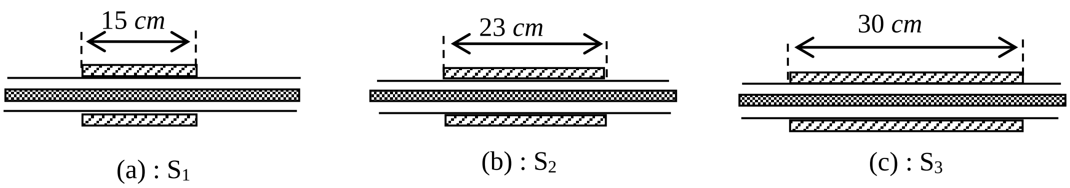

Fig.4: Schematic diagram of different length of the outer electrode (a) with outer electrode length *l*=15cm (b) *l*= 23 cm (c) *l*=30 cm. These systems are referred to as S_1, S_2 and S_3 respectively for the shake of convenience.

Air was supplied by an air pump and pure oxygen was supplied from a cylinder. When the discharge occurred, Ozone concentration was measured by ozone analyzer. To study the effect of the geometry of the ozone chamber, different length of electrode was used.

III. RESULTS AND DISCUSSION

A. Effect of applied voltage on ozone concentration

Fig.5 shows the variation of ozone concentration as a function of applied voltage for a fixed air flow rate of 2lit/min at 2mm gap with double barrier. It is evident that ozone concentration increases as the applied voltage increases. It is due to the reason that the increase in voltage increases the electrical energy density i.e. more energy transferred to the electrons, thereby increasing the possibility of collision of the air in the chamber. However, supplied energy may not always be sufficient for recombination of ions, radicals etc.

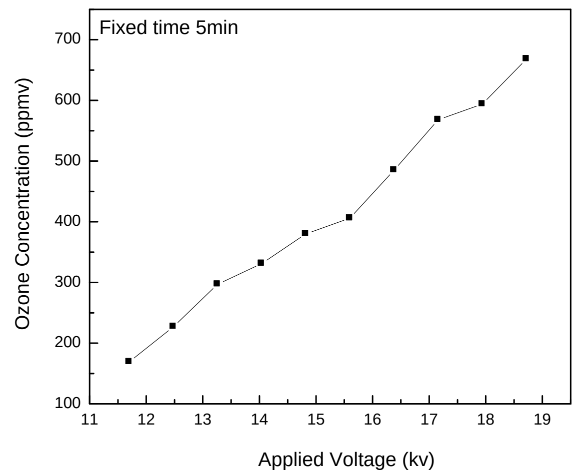

Fig.5 O_3 concentration vs Applied voltage for double barrier ozonizer at flow rate of air 2l/min

Fig.6 shows that ozone concentrations increases with increasing production time for same applied voltage. This is due to the fact that concentration of ozone increases with increasing the amount of non-elastic collisions with oxygen molecules.

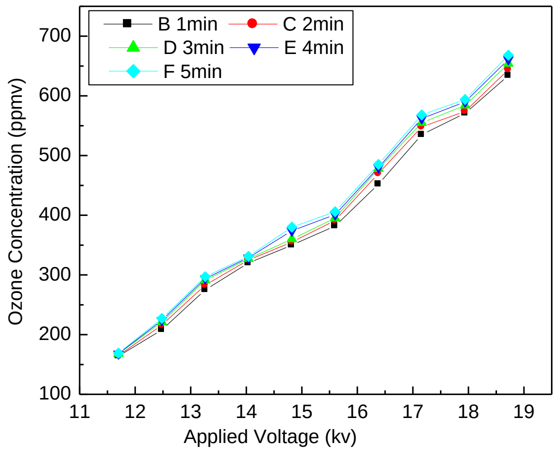

Fig.6. O_3 concentration as function of applied voltage for double barrier ozonizer for different time at flow rate of air 2l/min

Fig .7 shows the effect of voltage on the yield of ozone concentration for the oxygen flow in the range of 0.25 *l/min* to 4 *l/min*. For flow rate of 0.25l/*min*, ozone concentration increases as increase in voltage for few kV reaches maximum value 3700 *ppmv* and then it starts to decrease. For other flow rates, we found same trends.

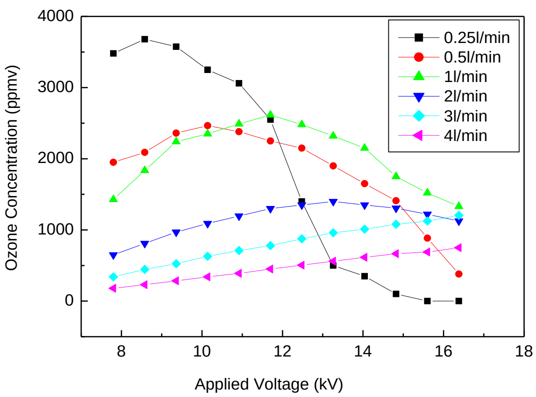

Fig.7 Ozone concentration Vs Applied voltage for different flow rates pure oxygen

B. Effect of gas flow rate on ozone concentration

The effect of oxygen flow rate on ozone concentration is shown in Fig.8. It shows that ozone concentration is lowered by the increased floe rate. This is because of the residence time of the gas on the ozone chamber inversely related to the gas flow rate, with an increased residence time providing time for a reaction to occur and a correspondingly higher ozone concentration to be produce.

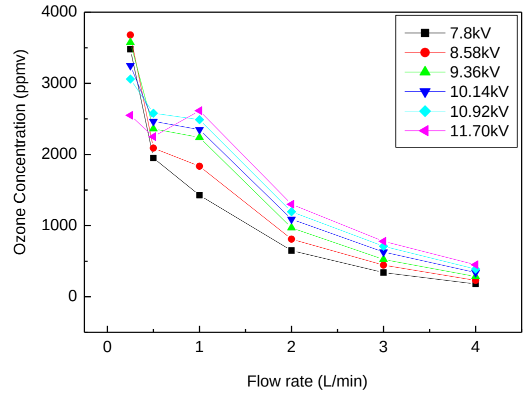

Fig.8 Ozone concentration Vs flow rate of O_2

C. Effect of length of electrode on ozone concentration

Fig.9 shows the Ozone concentration as a function of discharge voltage for different length of electrode (15 *cm*, 23 *cm* and 31 *cm*). It is observed that the production of ozone is higher for length of electrode 23 cm than other electrode length.

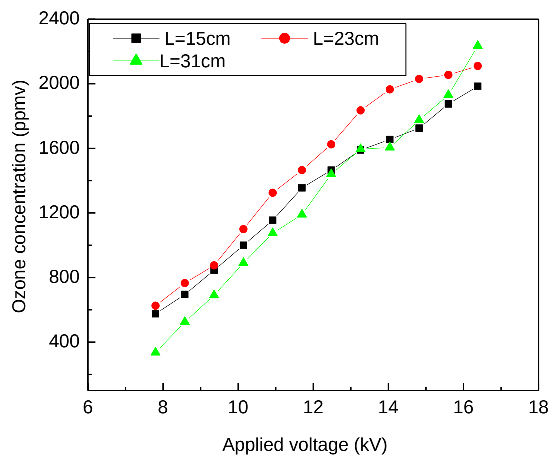

Fig.9 Ozone concentration as function of applied voltage for different electrode areas at flow rate of oxygen at 1L/mim

It is because of the resident time of the gas on the ozone chamber. Therefore, with an increased residence time providing them for reaction to occur and correspondingly higher ozone concentration occurs if the residence time is not enough for recombination process. However, the residence time in the device with 31 cm electrode length is more extended

D. Effect of gases on ozone concentration at different voltage

To study the concentration of ozone produced by oxygen as supplied gas and air, the experiment was repeated and result is shown in Fig.10. The concentration of ozone produced with air as fed gas is smaller than that of oxygen for same applied voltage. This is due to the composition of air which is more complex and consists of different species such as Ar,N_2, O_2, He, H_2 etc [14]. The main point of lower ozone concentration with feed gas air is the lower number of oxygen molecules in the unit volume of air compared with pure oxygen.

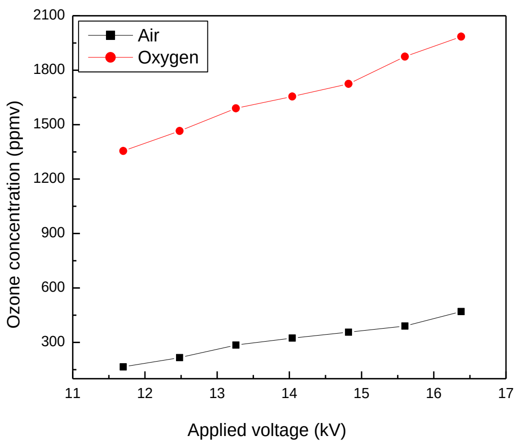

Fig.10 Ozone concentration as function of applied voltage for air and oxygen at flow rate of 1L/min

IV. CONCLUSION

The production of ozone by annular reactor in air and pure oxygen at atmospheric pressure with three lengths of outer (15cm, 23cm and 31cm), different flow rates and discharge voltage have been experimentally investigated. It was found that the concentration of ozone produced in dielectric barrier discharge increases with increasing applied voltage. The ozone concentration increases with increasing time in certain applied voltage. The comparison between ozone production using oxygen and air as feed gas had been made and found that ozone concentration was higher in the case of oxygen as feed gas than air for given flow rate and applied voltage. Also the comparison of ozone concentration produced in different electrode chamber length had been made and found that ozone concentration produced in outer electrode of length 23cm was more than the electrode length of 15cm and 31cm for same applied voltage and flow rate.

V. ACKNOWLEDGMENT

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