

## Ozone Generation Properties of Screw-type Electrode Ozonizer by Divided Outer Electrodes

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**Abstract**— Ozone became expected as a disinfectant for agricultural soil. Since ozone has strong bactericidal activity and no residual toxicity. Therefore the ozone generation system which suitable to soil sterilizations has been developing and ozone generation properties has been studying. Our ozone reactor has cylindrical shape, a screw electrode is used for an inner side electrode, and ozone was generated by dielectric barrier discharges. This time, we investigated influences on ozone generation characteristics when we used the outer electrode of 3cm or divided outer electrodes. And we also investigated the influence of the space of divided electrodes on ozone generation properties. As results, it was found that high concentration ozone had been generated relatively efficiently by dividing outer electrodes with wide electrode intervals.

**Keywords**-component; Ozone; Ozonizer; Screw Electrode; Dielectric Barrier Discharge (DBD); Electrical discharge

### I. INTRODUCTION

Ozone began to be widely used as a disinfectant. It is since ozone has strong oxidation ability, strong bactericidal activity and no residual toxicity. Ozone can generate from oxygen in the air. Here, it was determined that the methyl bromide ( $\text{CH}_3\text{Br}$ ), which is widely used as an agricultural chemical to sterilize soil, will be a disuse by 2015, because it brings on destruction of the ozone layer [1]. Then ozone became expected as a substitute for the methyl bromide [2]-[4]. Thus we have been developing an ozone generation system which is suitable to the soil sterilization, and investigating ozone generation properties of the ozone generation system. In our ozone generation system, ozone is generated by dielectric barrier discharges (DBD). An inner electrode of the ozone reactor is screw type electrode of stainless steel. Outer electrodes are copper plates which wrapped around the dielectric quartz glass tube. From our previous research, it was found that ozone generation properties depend on the kind of the source gas, the flow rate of the source gas, the applied voltage and the width of the outer electrode [5]-[9]. This time, influences of the outer electrode of 3cm or divided outer electrode of 1cm $\times$ 3 on ozone generation characteristics under applied voltages of 0-15.0kV, the source gas of pure oxygen and  $\text{O}_2$  flow rates of 0.1-1.0L/min. were investigated. And influences of intervals (1cm or 4cm) of divided electrodes on ozone generation properties were also investigated.

### II. EXPERIMENTAL METHODS

The ozone reactor which used in this research was shown in Fig. 1. Our ozone generator had cylindrical shape, the screw electrode (same shape to M12 ISO screw with screw thread interval of 1.75mm) made of stainless steel was used for the inside electrode and copper plates wound around an outside of the dielectric (quartz glass tube) was used for the outside electrode. Oxygen gas ( $\text{O}_2$ ) was used as a source gas of ozone generations. The source gas flowed in the gap of 1mm between the screw electrode and the dielectric, and ozone was generated by dielectric barrier discharges (DBD). DBD were made easily because electric fields become strong at near the tip of the screw by using the screw electrode. A photograph of divided outer electrodes of the ozone reactor was shown in Fig. 2. Each divided outer electrode was 1.0cm in width. In ozone generation experiments, in order to investigate the influence of the space of divided electrodes, the outer electrode of 3.0cm, outer electrodes of 1cm $\times$ 3 (Electrode intervals of 1.0cm) and outer electrodes of 1cm $\times$ 3 (Electrode intervals of 4.0cm) were used as the outer

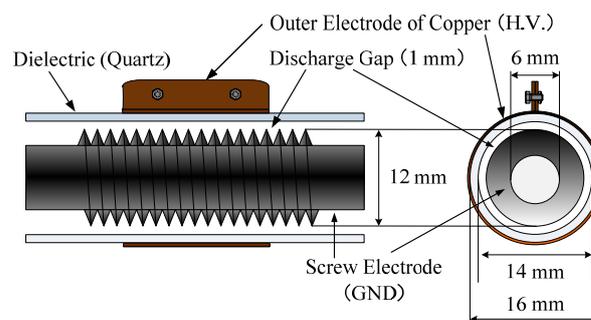


Figure 1. Schematic diagram of ozone reactor.

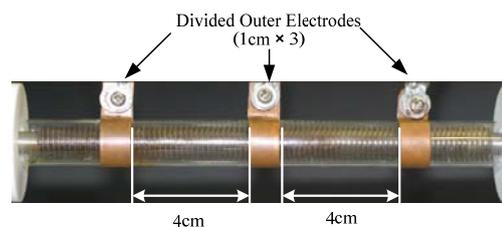


Figure 2. Divided outer electrodes of Ozone reactor

electrode of the ozone reactor.

This ozone reactor was set in the experimental circuit, and ozone generation experiments were carried out. Experimental set-ups of our ozone generation system were shown in Fig. 3. The applied voltage was supplied by using the neon transformer (Daihen, NA-1015P-H) which can be handled easily in the outdoor field. The flow rate of oxygen was adjusted by using a gas flowmeter (Koflok, RK-1200). The ozone concentration was measured by an ozone monitor (Ebara, EG-2001A). We made experiments under different conditions of applied voltages (0-15kV) and flow rates (0.1, 0.5, 1.0L/min.) of the oxygen. Experimental conditions of ozone generations were summarized in Table 1. At the time of ozone generations, the waveform of applied voltage and the discharge current waveform were measured and recorded by a digital oscilloscope (Iwatsu, DS-4264) through a high voltage probe (Iwatsu, HV-P60) and a resistor (50Ω). The amount of discharge charge of DBD was measured by using the capacitor (0.47μF). Discharge power was calculated from the Q-V Lissajous figure. Also, the ozone generation efficiency was calculated.

### III. RESULTS OF EXPERIMENTS

Photographs of discharges by applied voltage of 15kV at the ozone reactor with different outer electrodes were shown in Fig. 4. These photographs were taken by a CCD camera (CANON, EOS10D). A shutter of the CCD camera is opened for 2 seconds. In our screw electrode ozonizer, it was found that surface corona discharges occurred at the surface

of quartz tube from both edges of outer electrodes. These surface corona discharges are functioning as effective outer electrodes, and it makes outer electrodes effectively wider. Therefore spaces where DBD occurred become spread at the case of divided outer electrodes. And we guess that high concentration ozone would generate because discharge spaces extend and are more exposed to DBD. In the case of outer electrodes of 1cm×3 (electrode intervals of 4cm) (Fig. 4 (c)), the discharge space was largest, therefore the ozone concentration would become higher.

Relations between applied voltages and ozone concentrations with different outer electrodes at the O<sub>2</sub> flow rate of 0.1L/min. were shown in Fig. 5. In all cases, the ozone concentration increased with the rise of the applied voltage. Maximum values of the ozone concentration were

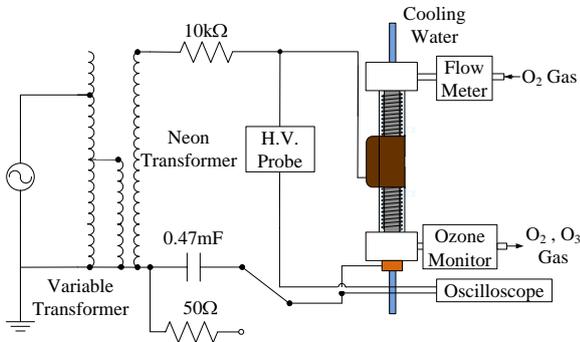
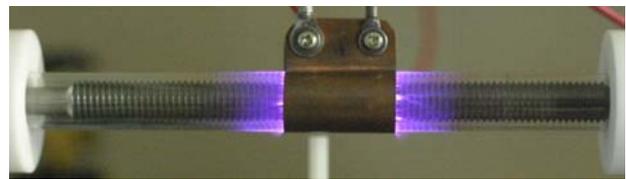


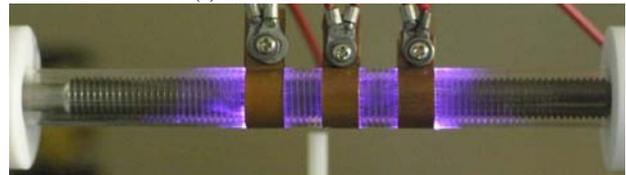
Figure 3. Experimental set-up of ozone generation

TABLE 1. EXPERIMENTAL CONDITION OF OZONE GENERATION.

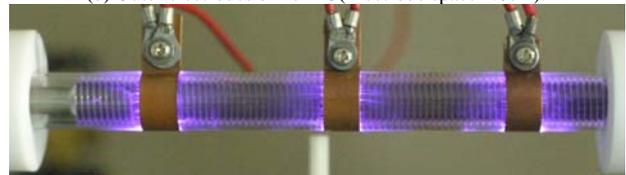
Source gas	Oxygen (99.995%)
Applied voltage	5.3~15kV
Frequency	60Hz
Flow rate	0.1, 0.5, 1.0L/min.
Gas pressure	1atm
Electrode geometry	Screw electrode
Outer electrodes	3cm
	1cm×3 (Electrode intervals of 1cm or 4cm)
Discharge gap	1mm



(a) Outer Electrode of 3.0cm.



(b) Outer electrodes of 1cm×3 (Electrode space 1.0cm).



(c) Outer electrodes of 1cm×3 (Electrode space 4.0cm).

Figure 4. Photographs of discharges at ozone reactor

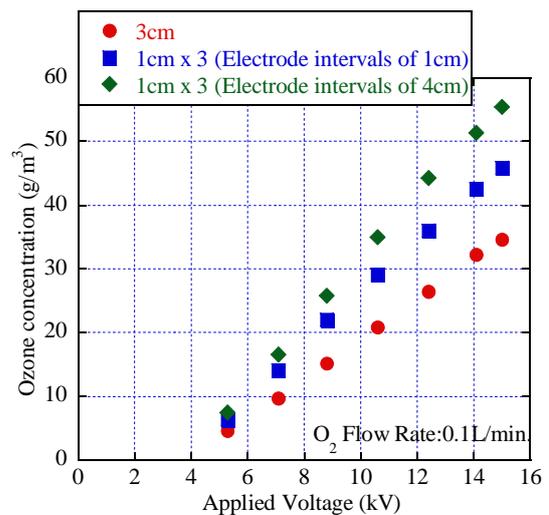


Figure 5. Relations between the applied voltages and ozone concentrations with different outer electrodes

34.6g/m<sup>3</sup> with the outer electrode of 3cm, 45.8g/m<sup>3</sup> with the outer electrode of 1cm×3 (electrode intervals of 1cm), and 55.4g/m<sup>3</sup> with the outer electrode of 1cm×3 (electrode intervals of 4cm). The ozone concentration was about 1.3 times in comparison with the outer electrode of 3cm and 1cm×3 (electrode intervals of 1cm), and was about 1.6 times in comparison with the outer electrode of 3cm and 1cm×3 (electrode intervals of 4cm). It was found that ozone concentrations became higher in our ozone reactor by dividing electrodes and extending discharge space.

Relations of applied voltages and ozone concentrations in the case of outer electrodes of 1cm×3(intervals 4cm) with different flow rates of O<sub>2</sub> were shown in Fig. 6. Ozone concentrations of cases of 0.1L/min. were about 4.0 times higher in comparison with cases of 0.1L/min. and cases of 0.5L/min., and were about 10 times higher in comparison with cases of 0.1L/min. and cases of 1.0L/min.. It was found that ozone concentrations increase as flow-rates of the O<sub>2</sub> source gas become lower. As the flow rate of the O<sub>2</sub> source gas becomes lower, the stay time of O<sub>2</sub> at the discharge space becomes long and O<sub>2</sub> were more exposed to DBD. Then we guess that higher concentration ozone was generated by the number of times of being exposed to DBD increases.

Relations of applied voltages and ozone generation efficiencies at the O<sub>2</sub> flow rate of 0.1L/min. with different outer electrodes were shown in Fig.7. Maximum values of the ozone generation efficiency were 146g/kWh with the outer electrode of 3cm, 141g/kWh with the outer electrode of 1cm×3 (electrode intervals of 1cm), and 140g/kWh with the outer electrode of 1cm×3 (electrode intervals of 4cm). Maximum values of ozone generation efficiencies concentration were almost same even by changing the outer electrodes. But in all cases, it was found that the ozone generation efficiency is decreasing linearly as the applied voltage becomes higher. Since source gas was heated by the energy of electrical discharges, these phenomena arise [10].

Relations of ozone concentrations and ozone generation

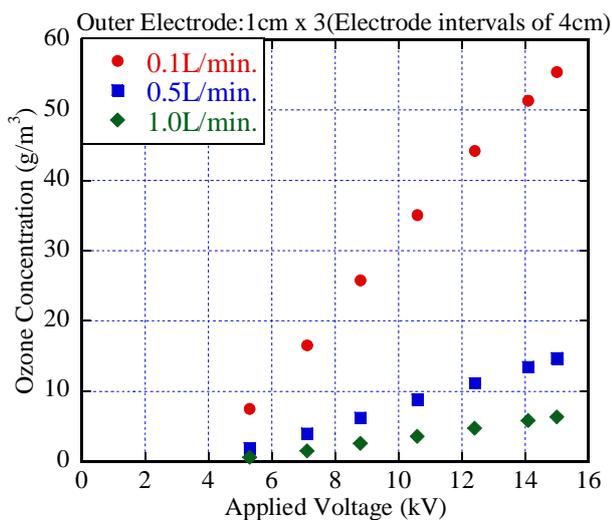


Figure 6. Relations of applied voltages and ozone concentrations of outer electrodes of 1cm×3(Electrode intervals of 4cm)

efficiencies at the O<sub>2</sub> flow rate of 0.1L/min. with different outer electrodes were shown in Fig. 8. In all cases, it was found that the ozone generation efficiency is decreasing linearly as the ozone concentration becomes higher. At ozone concentrations were lower than about 15g/m<sup>3</sup>; efficiencies of ozone generations were almost same even by changing outer electrodes. When ozone concentrations are higher than about 15g/m<sup>3</sup>, the decrease of the ozone generation efficiency was large only in the case of the outer electrode of 3cm. Causes of these differences are under consideration. We are guessing following things. The density of DBD is high at under the outer electrodes, and the density of DBD is lower at outside of outer electrodes edges. If the density of DBD is high, ozone will be generated more. But,

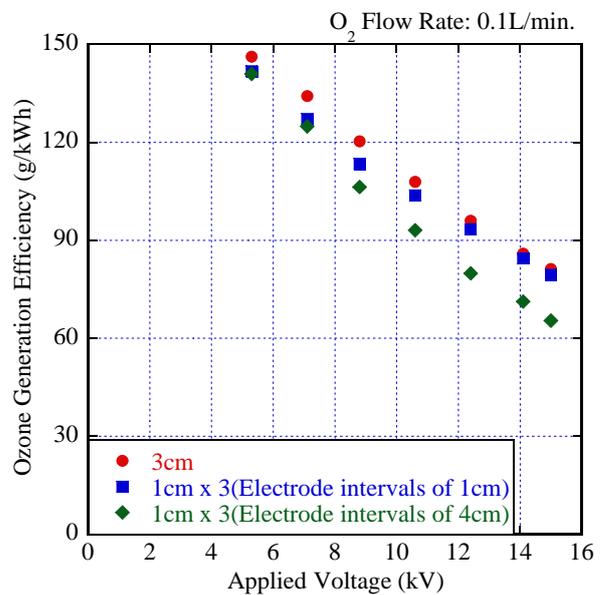


Figure 7. Relations of applied voltages and ozone generation efficiencies at O<sub>2</sub> flow rate of 0.1L/min.

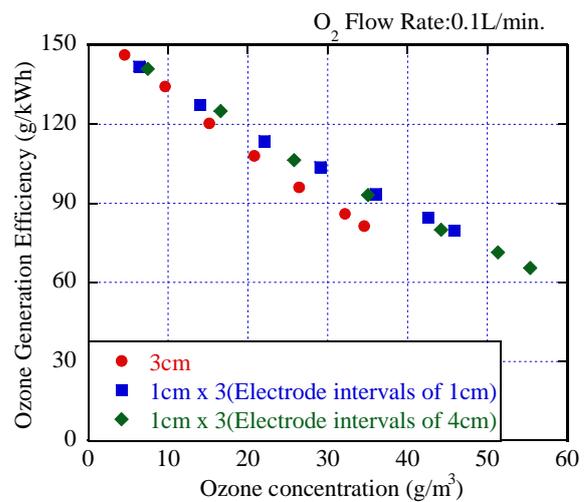


Figure 8. Relations of ozone concentrations and ozone generation efficiencies at O<sub>2</sub> flow rate of 0.1L/min.

if the density of DBD is too high, decompositions of the generated ozone are also occurred simultaneously. For such reason, we guess that, in case of divided electrodes, decompositions of the generated ozone would be slightly small and it obtained little bit high efficiency.

Relations of discharge powers and ozone yields in the case of outer electrode of 1cm×3(Electrode space of 4cm) with different flow rates of oxygen gas were shown in Fig. 9. In all cases, ozone yields increased with as discharge powers increased. Maximum values of the ozone yield were 332mg/h with 0.1L/min., 441mg/h with 0.5L/min. and 381mg/h with 1.0L/min.. It is found that the maximum ozone concentration of the case of 0.5L/min. is almost a one-fifth of the case of 0.1L/min., but the maximum value of ozone yield was obtained at the case of 0.5L/min..

#### IV. CONCLUSIONS

Ozone generation properties of screw-type electrode ozonizer by changing outer electrodes were investigated. This time, single outer electrode of 3cm width or divided outer electrode of 1cm×3 was used, and influences of intervals (1cm or 4cm) of divided electrodes on ozone generation properties were also investigated. Results obtained in this research are summarized as follows.

1) Surface corona discharges have been occurred at the outer surface of dielectric tube from both edges of outer electrodes. And surface corona discharges had extended the space where DBD generates.

2) Maximum value of the ozone concentration was 55.4g/m<sup>3</sup> with the outer electrode of 1cm×3 (electrode intervals of 4cm) at O<sub>2</sub> flow rate of 0.1L/min.

3) Maximum value of the ozone yield was 441mg/h with the outer electrode of 1cm×3 (electrode intervals of 4cm) at O<sub>2</sub> flow rate of 0.5L/min..

4) Maximum values of ozone generation efficiencies concentration were almost same even by changing the outer electrodes.

From these results, it was confirmed that surface discharges which occur at edges of outer electrode carry out the role of an effectual electrode. And it was found that higher concentration ozone is generable by dividing an outer electrode and expanding the interval in our ozone generation system.

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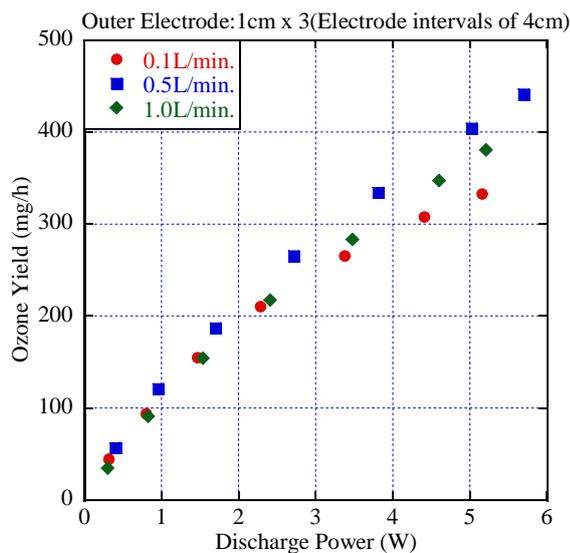


Figure 9. Relations of discharge powers and ozone yields of outer electrode of 1cm×3(Electrode intervals of 4cm)