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무성방전의 중첩을 이용한 다중방전형 오존발생기의 오존생성수율 개선

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ImprovementofOzoneYieldbyaMulti-DischargeTypeOzonizer UsingSuperpositionofSilentDischargePlasma

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Abstract - In order to improve ozone generation, we experimentally investigated the silent discharge plasma and ozone generation characteristics of a multi-discharge type ozonizer. Ozone in a multi-discharge type ozonizer is generated by superposition of a silent discharge plasma, which is simultaneously generated in separated discharge spaces. A multi-discharge type ozonizer is composed of three different kinds of superposed silent discharge type ozonizers, depending on the method of applying power to each electrode. We observed that the discharge period of the current pulse for a multi-discharge type ozonizer can be longer than that of silent discharge type ozonizer with two electrodes and one gap.Hence, ozone generation is improved up to 17185 ppm and 783 g/kwh for the superposed silent discharge type ozonizer for which an AC high voltages with a 180 phase difference were applied to the internal electrode and the external electrode, respectively, with the central electrode being ground

1. Introduction

Ozone has been used widely for the treatment of water and exhausted smoke, deodorization, color removal, disinfection, etc. because of its strong oxidation. It is well known that the high-pressure barrier discharge plasma (the so-called silent discharge plasma) has become one of the powerful methods for ozone production since the pioneering work by Siemens [1, 2]. Most technical silent discharge type ozonizers use a pair of electrodes.

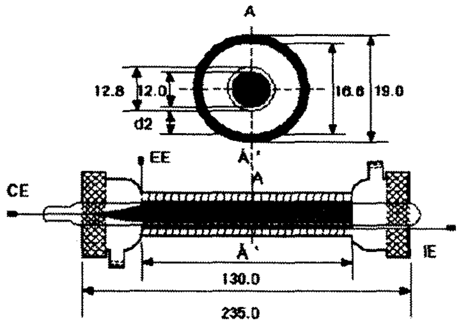
Silent discharge type ozonizers consist of a narrow discharge space, formed between a dielectric and a high voltage electrode, and ground electrode outside of the dielectric. The process gas, usually air or oxygen, is passed through an arrow annular discharge gap, and through the plasma chemistry of a micro-discharges, it is partially converted into ozone. [3, 4]. Charge is accumulated in the area where micro-discharges reach the dielectric when the current is initiated in micro-discharges. The micro-discharge is interrupted before leader formation or spark discharge. Since the process gas in the discharge column is not heated up, current flow stops below the breakdown field. By repetition of these sequences, micro-discharges are initiated and choked [5, 6]. In the silent discharge type ozonizer broad application of ozone is known to be hindered primarily because of its low ozone yield. The 1200 g/kwh theoretical ozone yield is calculated by using thermo-chemical theory [7]. So far, there have been many attempts to improve the efficiency of ozone generation for industrial uses of such discharges [8-12].

In this study, a new multi-discharge type ozonizer with two spaces and three electrodes for improvement of the ozone yield is experimentally proposed to investigate the discharge and the ozone generation characteristics of a superposition silent discharge plasma. Depending on the power supply used for each electrode, the multi-discharge type ozonizer was composed of three kinds of superposed silent discharge type ozonizers, which are IESDO, CESDO and CISDO. For superposed silent discharge type ozonizer, the characteristics of the discharge voltage and current waveforms were analyzed at a discharge power of 8 W and supplied oxygen gas flow rate of 2 l/min. For various quantities of supplied oxygen gas, the ozone concentration and yield were investigated as a function of the number of a superposed silent discharge type ozonizers. The ozone generation yield was estimated as a function of the rate of supplied oxygen gas for each superposed silent discharge type ozonizer. The environmental application of a multi-discharge type ozonizer for dyeing wastewater was also investigat

2. EXPERIMENTAL APPARATUS AND METHOD

Figure 1 shows a schematic diagram of a multi-discharge type ozonizer with a coaxial double cylindrical system. A multi-discharge type ozonizer consists of three electrodes (central electrode, internal electrode and external electrode), two dielectrics (flint glass and Pyrex glass), and two gap spaces (the discharge space between central electrode and the internal electrode, and the discharge space between the internal electrode and the external electrode).

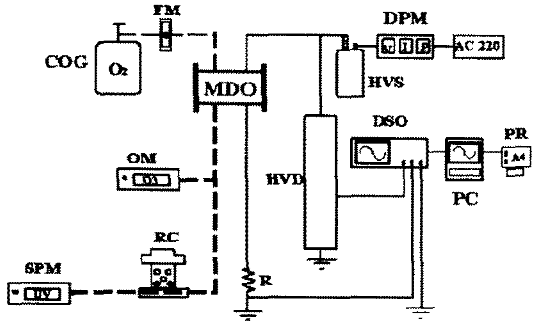
The central electrode was made with a low pressure glow discharge plasma lamp that installed a cone ferrite oxide electrode inside cylindrical flint glass tube with a thickness of 1.0 mm and an outside diameter of 12 mm. The internal electrode was manufactured with stainless steel mesh 0.035 mm thick and 130 mm long, that turns around the central electrode, keeping the gap between the central electrode and the inner discharge space at 0.4 mm. The external electrode was a 1.0 mm thick copper coil wrapped around the outside surface of Pyrex glass in 5 mm interval to a length of 130 mm, keeping the space between the internal electrode and the outer discharge space at 1.9 mm. One of the three electrodes was grounded, and AC high voltage, with a 180 phase difference, were applied to the other two electrodes.



unit: mm
CE: central electrode
IE: internal electrode
EE: external electrode

Fig. 1. Schematic diagram of the multi-discharge type ozonizer with a coaxial double cylindrical system.

Figure 2 presents a schematic diagram of the experimental setup. The dotted line shows the flow of supplied oxygen gas and ozonized gas, and the solid line is the connecting circuit line for the power source and the measurement apparatus.



FM: flow meter
DPM: digital power meter
COG: commercial oxygen gas
MDO: multi-discharge type ozonizer
HVS: high voltage source
OM: ozone monitor
HVD: high voltage divider
DSO: digital storage oscilloscope
PC: personal computer
PR: print
SPM: spectrophotometer
RC: reaction chamber
R: non- inductivity resistor

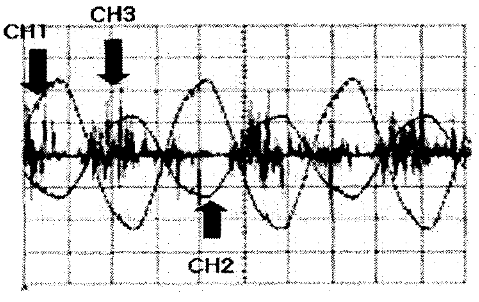
Fig. 2. Schematic diagram of the experimental setup consisting of a multi-discharge type ozonizer using superposition of a silent discharge plasma.

The discharge power was measured with a digital power meter (Light Star, DPM 20, Korea) at the input terminal of the AC power source. This included discharge power of the superposed silent discharge ozonizer, the high voltage transformer loss, and the power line loss. The discharge voltage, current, and waveform were measured with a digital storage oscilloscope (Lecroy Model 9350AL, USA), a high voltage divider (Pulse Electronics Model EP-50K 2000:1, Japan), and a 50 non-inductive resistor at a supplied oxygen gas 2 l/min and a discharge power of 8 W. Also, these values were displayed using a PC and were printed.

Next, the ozone concentration of the multi-discharge type ozonizer was measured with an ozone monitor when the number of each superposed silent discharge ozonizer was one or three. The ozone yield was calculated by using the ozone concentration and the discharge power. In order to research the dependence of the ozone generation characteristics on the shape of the superposed silent discharge type ozonizer, we compared the ozone yield rates for IESDO, CESDO, and CISDO.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 shows the discharge voltage and current waveforms at a discharge power of 8 W and a supplied oxygen gas flow rate of 2 l/min for IESDO, CESDO, and CISDO.



CH1 (central electrode): 4 kV/div
CH2 (internal electrode): 10 kV/div
CH3 (central electrode): 40 mA/div, 5 ms/div
(a) IESDO

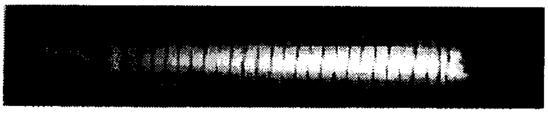
CH1 (central electrode): 4 kV/div
CH2 (external electrode): 10 kV/div
CH3 (internal electrode): 40 mA/div, 5 ms/div
(b) CESDO

CH1 (central electrode): 4 kV/div
CH2 (internal electrode): 10 kV/div
CH3 (external electrode): 10 mA/div, 5 ms/div
(c) CISDO

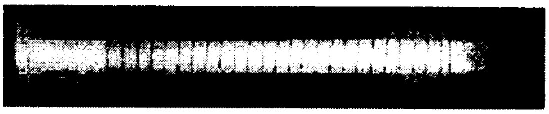
Fig. 3. Discharge voltage and current waveforms at a discharge power of 8 W and a supplied oxygen gas flow of 2 l/min for each superposed discharge type ozonizer.

Figure 4 displays photographs of the discharge phenomena in IESDO, CESDO, and CISDO at a discharge power of 8 W and a supplied oxygen gas flow rate of 2 l/min.

(a) IESDO



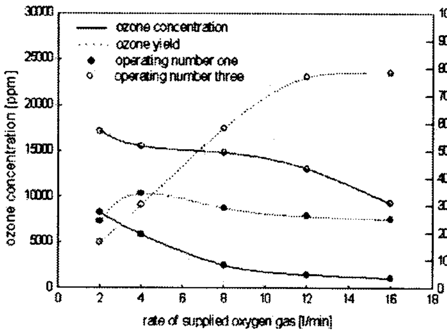
(b) CESDO



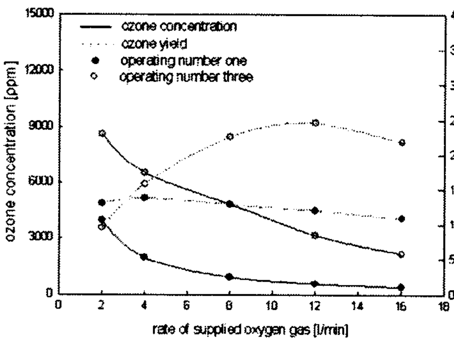
(c) CISDO

Fig. 4. Photographs of the discharge phenomena at a discharge power of 8 W and a supplied oxygen gas flow of 2 l/min for each superposed discharge type ozonizer.

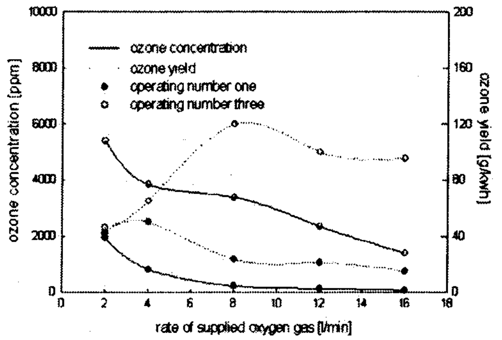
Figure 5 shows ozone concentration and yield characteristics with variation of quantity of supplied oxygen gas at discharge power each 8 W and 24W when number of IESDO, CESDO and CISDO are one and three. The ozone concentration is proportional to operating number of superposed discharge type ozonizers, but inversely proportional to the rate of supplied oxygen gas. The maximum values of the ozone concentration in Figure 5 (a), (b) and (c) were, respectively, 17185 ppm, 8606 ppm, and 5407 ppm when the operating number of superposed discharge type ozonizer was three and the oxygen gas was supplied at a rate of 2 l/min.



(a) IESDO



(b) CESDO



(c) CISDO

Fig. 5. Ozone concentration and yield as functions of the rate of supplied oxygen gas at discharge powers of 8 W and 24 W when number of each SDO is one and three.

As the rate of supplied oxygen gas was decreased, the time that oxygen molecules stay in discharge area was prolonged, and ozone generation reactions occurred vigorously:

$$O_2 + e \rightarrow 2O + e \quad (1)$$
$$O + O_2 \rightarrow O_3 \quad (2)$$
$$O_2 + e \rightarrow O_2* + e \quad (3)$$
$$O_2* + e \rightarrow O + O + e \quad (4)$$

where e, O, O_2 and O_3 are electrons, oxygen atoms, oxygen molecules in the ground state, and ozone, respectively.

The oxygen gas passing time, T, of the discharge space (length 130 mm, volume 13432 mm3) and the passing time, t, of the oxygen in a spiral type external electrode are shown in Table 1 for various supplied oxygen gas flow rates, the ozone concentration is proportional to T and t.

Table 1. Passing time, T, of the discharge space and passing time, t, of the spiral of the external electrode.

Rate of supplied oxygen gas [l/min]	T [ms]	t [ms]
2	448.0	18.0
4	224.0	9.0
8	112.0	4.5
12	75.0	3.0
16	56.0	2.3

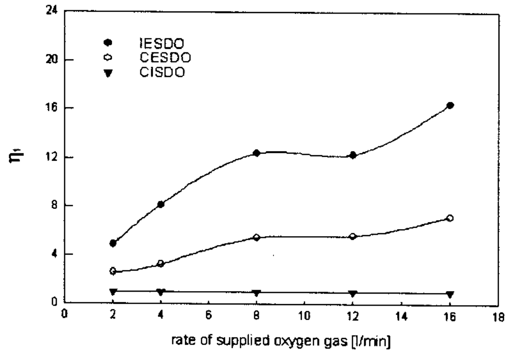
The maximum values of the ozone yield in Figure 5 (a), (b) and (c) were, respectively, 783 g/kwh, 246 g/kwh, and 120 g/kwh for three operating superposed discharge type ozonizers .

When the oxygen gas was supplied at a rate lower than 4 l/min for three operating ozonizers, the ozone yield was low compared to that for one operating ozonizer. This results from ozone concentration, space density augmentation, and ozone dissociation reactions such as

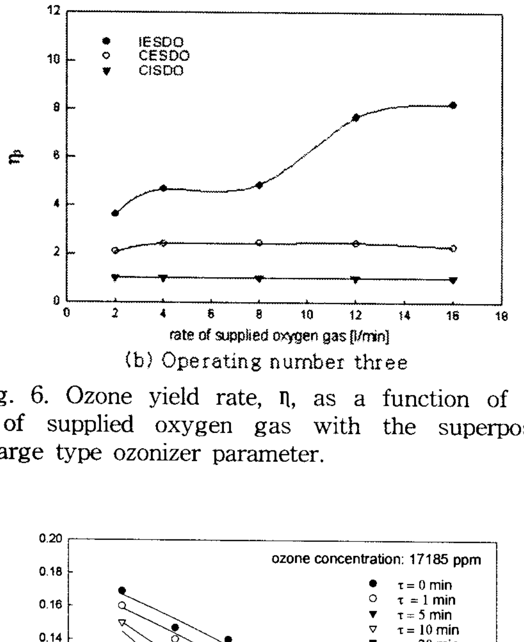
$$O + O_3 \rightarrow 2O_2 \quad (5)$$
$$O_3 + e \rightarrow O_2 + O + e \quad (6)$$

Figure 6 shows the ozone yield rate, η, as a function of the rate of supplied oxygen gas for the three kinds of superposed discharge type ozonizers. At this time, ozone yield rate, was compared with ozone yield of IESDO and CESDO about ozone yield of CISDO.

Figures 7 and 8 depict the decolorization effect of wastewater by using IESDO.



(a) Operating number one



(b) Operating number three

Fig. 6. Ozone yield rate, η, as a function of the rate of supplied oxygen gas with the superposed discharge type ozonizer parameter.

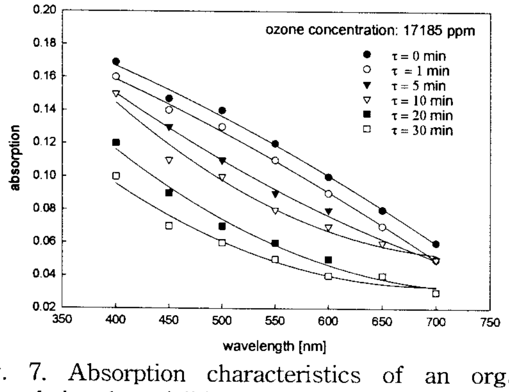
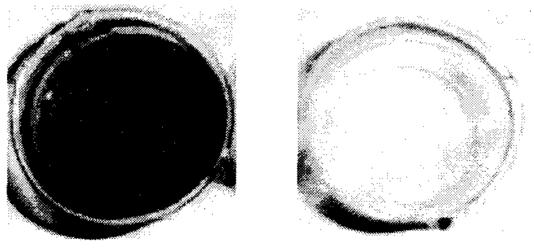


Fig. 7. Absorption characteristics of an organic compound in the visible region for various contact times, , of ozone and dyeing wastewater.

Figure 8 shows photographs of a dyeing wastewater when is 1 min and 30 min, respectively.



(a) τ=1 min (b) τ=30 min

Fig. 8. Photographs of the dyeing wastewater when is 1 min and 30 min, respectively.

4. CONCLUSIONS

The following results were obtained:

(1) Among the three electrodes that make up the multi-discharge type ozonizer, AC high voltages with a 180 phase difference were applied to two electrodes and the other electrode was grounded. The three kinds of superposed discharge type ozonizers had different discharge and ozone generation characteristics.

(2) The multi-discharge type ozonizer had improved ozone generation characteristics compared to the silent discharge type ozonizer due to reiteration of the silent discharge plasma that occurred in two discharge spaces.

(3) Among the three kinds of superposed discharge type ozonizers, IESDO had excellent ozone generation characteristics.

(4) The maximum values of the ozone concentration and yield of the multi-discharge type ozonizer were 17185 ppm and 783 g/kwh, respectively.

(5) When dyeing wastewater was reacted with 17185 ppm ozone, it become almost white after 30 min.

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