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Process Development Based on Nano-Seconds Pulsed Discharge
ナノ秒パルス放電プラズマプロセスの実用化へ向けて

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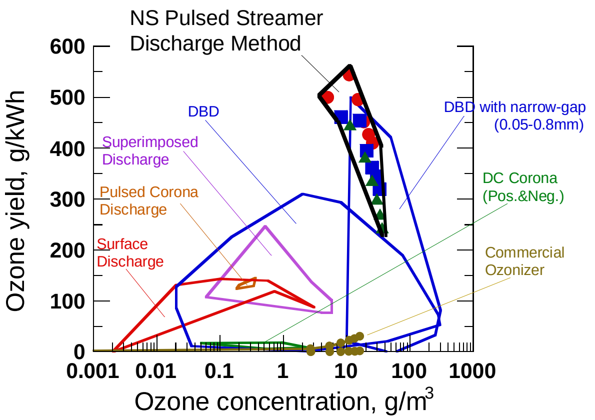
Energy efficient generation of ozone is very important because ozone is being used increasingly in a wide range of industrial applications. In this study, ultra-short duration pulsed streamer discharges with a duration of 5 ns hava been used to produce ozone in a wire-to-cylinder electrode reactor. The triaxial Blumlein configuration is used for the nano-seconds pulsed generator. Ozone concentration and ozone production yield were measured at various applied voltages (50 to 70 kV), and pulse repetitions (10 to 60 pps) at atomospheric pressure in oxygen and air. The experimental results showed that the ozone concentration (g/m^3) increased with increasing applied pulse voltage and pulse repetition rate. Higher ozone concentrations were obtained in the oxygen-fed ozonizer than in the air-fed ozonizer. The ozone production yield (g/kWh) was high at low ozone concentration, and higher ozone yield was obtained with lower applied voltages. Characterization maps of ozonizers based on different discharge methods (nano-seconds pulsed discharge, DBD, DBD with narrow-gap, surface discharge, pulsed corona discharge, DC corona, superimposed discharge methods and a commercial ozonizer) were presented with oxygen-fed and air-fed cases. A nano-seconds pulsed discharge showed the highest ozone yield in the characterization maps for both the oxygen-fed and air-fed cases, where the highest ozone yield were 544 and 239 g/kWh in the oxygen-fed and air-fed cases, respectively.

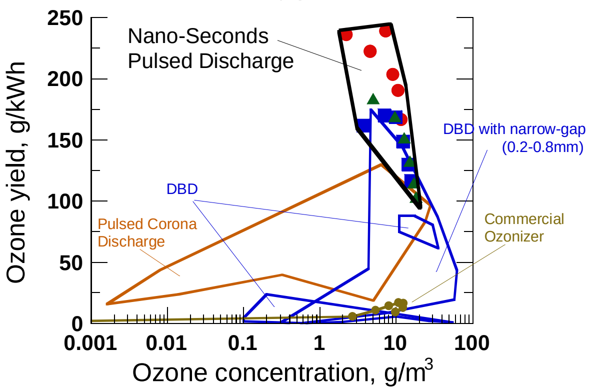
1. Characteristics map of Ozonizer Based on Discharge Plasmas

Characterization maps of ozonizers based on different discharge methods are shown in Fig. 1. In Fig. 1, results of ozone generation using nano-seconds pulsed discharge, DBD, DBD with narrow-electrode gap, surface discharge, pulsed corona discharge, DC corona, superimposed discharge (surface discharge & DBD, surface discharge & pulsed corona discharge) methods and a commercial ozonizer are displayed for both oxygen-fed (a) and air-fed (b) cases, respectively. In Fig. 1, the right-upper region identifies the better performance of an ozonizer. It should be noted that the ozone yield resulting from the commercial ozonizer was evaluated from the plug-in energy while the others were examined using the discharge energy. In the case of the oxygen-fed ozonizer (Fig 1(a)), the highest ozone yield was obtained by the nano-sconds pulsed discharge method with 544 g/kWh of peak yield in the range of 4.9-36.5 g/m3 ozone ocncentration. The second highest ozone yield resulted from DBD with a narrow-gap method which was 500 g/kWh in the range of 10-300 g/m^3 ozone concentration. The DBD method covered a wide range of ozone concentration of 0.02-299 g/m3 where the ozone yield was up to 310 g/kWh. Further low ozone concentration can be obtained by surface discharge of 0.002-3 g/m^3 where the ozone yield was under 143 g/kWh. The DC corona method showed very low ozone yield, and the pulsed corona discharge showed a narrow range of ozone concentration. The result of the superimposed discharge method was completely covered by the area of the DBD method. The ozone yield of an oxygen-fed type commercial ozonizer using DBD with a narrow-gap method was 1.9 g/kWh at 16 g/m^3 of ozone concentration. Since this low energy efficiency is mainly due to power consumption in the PSA oxygen generation unit, the ozone yield without the PSA unit was also measured, and the result was 30.5 g/kWh at 16 g/m^3. For the air-fed ozonizer (Fig. 1(b)), the highest ozone yield was also obtained by the nano-seconds pulsed discharge method with 239 g/kWh of peak yield in the range of 2.2-18.3 g/m^3 ozone concentration. The second highest ozone yield resulted from DBD with a narrow-gap method which was 175 g/kWh in the range of 0.3-62 g/m^3 ozone concentration. The DBD method seems to be not as efficient as the pulsed corona method in the air-fed case. The ozone yield by the pulsed corona method showed a wide range of ozone concentrations, typically 0.001-28 g/m^3 with a maximum ozone yield of 130 g/kWh. Finally, the ozone yield of an air-fed type commercial ozonizer using the DBD with a narrow-gap method was 17 g/kWh at 10 g/m^3 of ozone concentration.

The reason why the nano-seconds pulsed discharge gave the highest ozone yield is due to its unique discharge phenomena. Fig. 2 shows streak images of (a) a pulsed discharge and (b) a nano-seconds pulsed discharge in a coaxial cylindrical electrode geometry. From Fig. 2(a), a discharge with a pulse duration of 100 ns shows two discharge phases: a streamer discharge which initiates in the vicinity of the central electrode and propagates toward the outer electrode; and a glow-like discharge which is generated after full development of the streamer discharge. It was also observed that the plasma impedance was different for the streamer and the glow-like discharges. Moreover, a rise of the gas temperature occurred during the glow-like discharge phase. These factors could induce energy losses due to the impedance mismatching between the pulsed power generator and discharge reactor, with gas thermalization from plasma-enhanced chemical reactions during gas treatment. On the other hand, the discharge with a pulse duration of 5 ns, shown in Fig. 2(b), indicates that the discharge history finishes before it shifts to the glow-like discharge phase. Consequently, the impedance matching between the power generator and discharge reactor can be improved and the gas heating problem can be minimized.

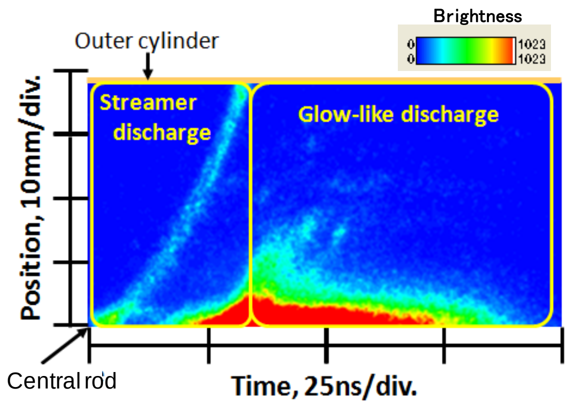


(a) Oxygen-fed

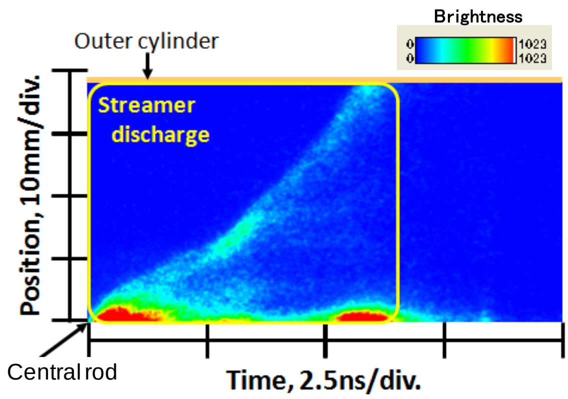


(b) Air-fed

Figure 1. Characteristics map of ozonizers based on different discharge methods.



(a) Pulsed duration of 100 ns.



(b) Pulse duration of 5 ns.

Figure 2. Streak images of (a) a pulsed discharge and (b) a nano-seconds pulsed discharge in a coaxial cylindrical electrode reactor.

2. Conclusion

Characterization maps of ozonizers based on different discharge methods (nano-seconds pulsed discharge, DBD, DBD with narrow-gap, surface discharge, pulsed corona discharge, DC corona, superimposed discharge (surface discharge & DBD, surface discharge & pulsed corona discharge) methods and a commercial ozonizer) were presented for the oxygen-fed and air-fed cases. The following conclusions have been deduced:

A nano-seconds pulsed discharge showed the highest ozone yield in the characterization maps for both the oxygen-fed and air-fed cases.

References

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