SHORT PAPER

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Improvement of the Corona Discharge in Dry Air in Order to Obtain Ozone With Maximum Efficiency†

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An ozone production system based on a corona discharge in dry air is described. The ozone generator has a novel type of electrode system, theoretically optimized, and with double discharge surfaces. A specially designed high voltage supply was used, which generates the required pulses according to a time program calculated to increase energy efficiency. The described experimental system was found to have a reduced power consumption per gram of ozone produced and also greater ozone production per electrode area than other systems that use a classical arrangement of electrodes.

Keywords: *Corona discharge; ozone production; efficiency*

The need for increasing amounts of ozone[1–4] makes its production with high efficiency important. In this context, the results of corona discharge theories[5–9] have been applied to improve ozone production methods.[10]

This paper presents a system of electrodes with double discharge surfaces, geometrically optimized, and also a high voltage (HV) source which permits the onset of corona discharge at an optimum reduced field, according to a specific program, this favoring the rate of ozone production while inhibiting the rate of its decomposition.

THEORY

The analytical approach to the corona discharge in terms of microscopic theory[11] is difficult owing to the non-linear processes occurring in the plasma.

In order to obtain the maximum density of the corona conduction current with minimum energy consumption, we have calculated the discharge onset voltage to be applied to a cylindrical, co-axial system of electrodes. The value[12] obtained for the optimum reduced field is $(E/p)_{\text{opt}} = 273\,773$ V per m Pa.

In order to increase the area of the corona discharge for a given volume of ozone generated, an electrode system is proposed (Fig. 1).

Preserving the conditions discussed above, we have used eqns. (1) and (2) to optimize geometrically the electrode system and to determine the amplitude, V, of the alternating potential applied to the HV electrode.

$$R_1\left(\ln\frac{R_1}{R_0}+\frac{1}{\varepsilon_1}\ln\frac{R_1+d_1}{R_1}\right)= \tag{1}$$

$$(R_1+d_1+d_2)\left(\ln\frac{R_2}{R_1+d_1+d_2}+\frac{1}{\varepsilon_2}\ln\frac{R_1+d_1+d_2}{R_1+d_1}\right)$$

$$V=V_{\text{d}}\left(1+\frac{1}{\varepsilon_2}\ln\frac{R_1+d_1+d_2}{R_1+d_1}\Big/\ln\frac{R_2}{R_1+d_1+d_2}\right) \tag{2}$$

where ε_1 and ε_2 are the electrical permittivities of the first and second dielectric layers (as numbered in Fig. 1), V_{d} is the electrical potential present on the two dielectric surfaces which are in contact with the corona discharge plasma. The other symbols are self-explanatory from Fig. 1.

Using for the first dielectric layer a Pyrom glass having $\varepsilon_1=4.4$ and $d_1=3$ mm and for the second dielectric layer an enamel having $\varepsilon_2=5.6$ and $d_2=2$ mm, the following geometric dimensions were obtained for the electrode system (Fig. 1): $R_0=30$ mm, $R_1=33$ mm and $R_2=41$ mm.

The optimum reduced field (2) for corona discharge onset in dry air at a dew point of -50 °C is obtained by applying to the HV electrode an alternating potential with an amplitude, V, of 20 019 kV, a value which gives $V_{\text{d}}=15\,802$ kV.

A frequency of 1 kHz was chosen to allow the half-period to be longer than the sum of the durations of the processes of molecular oxygen dissociation (≈10 µs)[13] and reaction[11] between molecular and atomic oxygen (≈10–20 µs).[13] An almost linear dependence of ozone concentration yield on applied frequency has been observed in previous experiments, up to this frequency (1 kHz).[13]

The HV is applied according to the time program shown in Fig. 2. The magnitude of the active period has to take into account the time necessary for ozone formation, $\approx 10^{-3}$ s, the air flow velocity through the discharge zone, $\approx 10^{-1}$ m s^{-1}, and the length of this zone, $L=500$ mm (electrode system length).

The relaxation period was introduced to increase the concentration of molecular oxygen in the discharge region and to decrease that of the ozone formed, so that when a new discharge is onset, there will be higher rates of molecular oxygen dissociation and reduced rates of ozone dissociation.

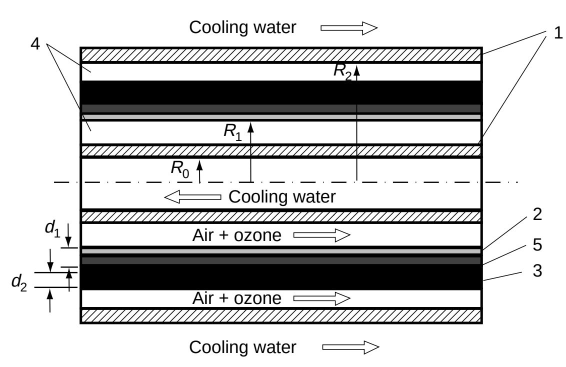

Fig. 1 Electrode system of the ozone generator: 1, grounded electrodes; 2, first dielectric layer; 3, second dielectric layer; 4, discharge volume; and 5, high voltage electrode.

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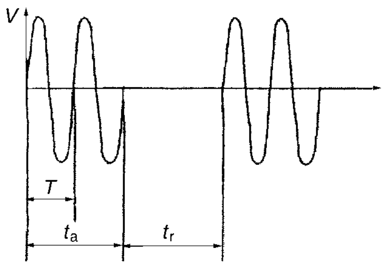

Fig. 2 Time program of the applied high voltage pulses. t_a = active period; t_r = relaxation period; $T = 1/f$ = period of the applied high voltage.

Values of the two time periods were optimized experimentally as described in the following section.

Following the time program (Fig. 2) for HV pulses, the ozone generator would have a continuous work regime which provides a decrease in the specific energy consumed for ozone production.

EXPERIMENTAL SYSTEM

The experimental system is presented schematically in Fig. 3.

Compressed air enters the air-filter (6) where mechanical impurities and condensed water are retained; the air then enters the drying-aggregate (5). This aggregate contains two columns filled with molecular sieve 13X, which function in tandem such that while one column dries the air the other regenerates itself. Regeneration is achieved by pressure difference, using part of the dried air.

The pressure regulator (4) reduces the air pressure from 4–6 bar in the drying-aggregate to 0.2–0.8 bar in the ozone generator (1).

The ozone generator (1) has the electrode system presented in Fig. 1 and is cooled by a water flow of 150 l h^{-1}.

The HV supply [blocks (7)–(9) in Fig. 3] has a power of 1.2 kW, sufficient to onset corona discharge between the electrode system, which has a capacitance of $\approx 10^{-9}$ F. The HV supply is 220 V and 50 Hz. It generates alternating pulses having adjustable frequencies between 0.20 and 1.2 kHz and adjustable amplitudes between 2 and 21 kV. The active period (Fig. 2) is adjustable between 1 and 120 s and the relaxation period between 0 and 1 s.

A circuit diagram of the HV supply is presented in Fig. 4. The commanded rectifier (1), which outputs 20–250 V, feeds an inverter with transistors (2) and (3), which have as charge a ferrite core, and a step-up transformer (4) the secondary winding of which is connected to the electrode system. This transformer has a ratio of 1/85 and a power of 1.2 kW. The two transistors (2) and (3) of the inverter are commanded by a push–pull oscillator (5) and two monostable blocks (6).

The oscillation frequency is adjusted by means of a potentiometer in the oscillator block. The active and relaxation times are set by the block (8) which acts on the oscillator. The output voltage amplitude is adjusted by the commanded rectifier.

Protection of the two transistors in the inverter from excess current is effected by placing in their emitters a calibrated resistance (9) that serves to measure the current through the two transistors and which attains a maximum prescribed value; a comparator block (10) resets the two monostable blocks (6).

Protection of the transistor collectors in the inverter from excess voltage is realized by connecting them to a series protection group (11).

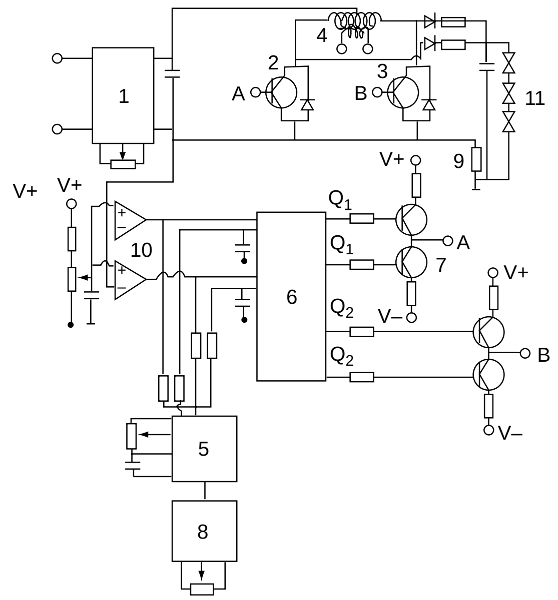

Fig. 4 Schematic diagram of the high voltage supply. 1, Commanded rectifier; 2 and 3, transistors in the inverter block; 4, transformer; 5, oscillator; 6, monostable block; 7, commanding transistors; 8, time programming block; 9, calibrated resistance; 10, comparator block; and 11, protection group.

TESTS AND RESULTS

After functional testing of each element of the system (Fig. 3), a series of tests was run on the whole assembly in order to determine the optimum values for some of its parameters and also to determine its overall performance.

The ozone production flow depends on several parameters.

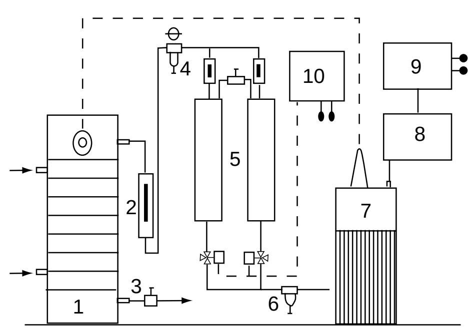

Fig. 3 Experimental system layout. 1, Ozone generator; 2, rotameter; 3, valve; 4, pressure reductor; 5, drying-aggregate; 6, air-filter; 7, transformer; 8, inverter; 9, rectifier; and 10, valve control block.

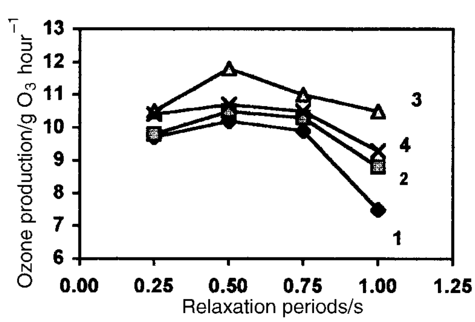

Fig. 5 Variation of ozone production with relaxation period. 1, t_a = 1 s; 2, t = 40 s; 3, t_a = 80 s; and 4, t_a = 120 s. The following parameters were fixed: V = 20.019 kV; f = 1 kHz; Q_{air} = 1 m^3 h^{-1}; and Q_{water} = 150 l h^{-1}.

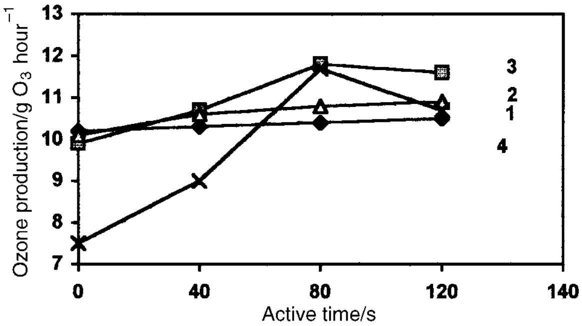

Fig. 6 Variation of ozone production with active period. 1, $t_r = 0.25$ s; 2, $t_r = 0.5$ s; 3, $t_r = 0.75$ s; and 4, $t_r = 1$ s. The following parameters were fixed: $V = 20.019$ kV; $f = 1$ kHz; $Q_{air} = 1$ m^3 h^{-1}; and $Q_{water} = 150$ l h^{-1}.

Some of these were fixed as a result of theoretical calculations and other assumptions discussed above: HV value $V = 20.019$ kV; HV frequency $f = 1$ kHz; cooling water flow $Q_{water} = 150$ l h^{-1}. Other parameters such as the active period, t_a (Fig. 2), the relaxation period, t_r, and dry air flow, Q_{air}, were optimized experimentally as follows.

Each of these three parameters was varied over a certain range of values while the other two were kept constant and the ozone production flow was recorded. A set of curves was thus obtained as shown in Figs. 5–7.

From these curves, the optimum values of the three parameters were established, as those that maximize ozone production flow. The values were: active period $t_a = 80$ s; relaxation period $t_r = 0.5$ s; and air flow $Q_{air} = 1$ m^3 h^{-1}.

The electrical power consumption for one unit of ozone produced was calculated by calorimetric measurements of the cooling water in the ozone generator. A value below 20 W per gram of ozone was obtained in preliminary tests without further optimization. This value is very promising compared with those reported in the literature[10,14] for other ozone generators, *viz.*, around 30 W per gram of ozone.

The ozone production per unit of electrode area was found to be almost twice as large as that of other ozone generators having a classical system of electrodes.

CONCLUSIONS

The theoretical principles for an ozone production system have been discussed. The electrode system within which the corona discharge is onset has been optimized theoretically and has a double discharge area.

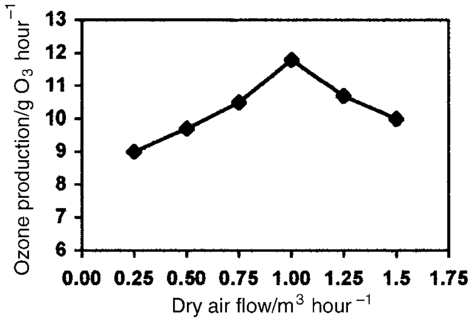

Fig. 7 Variation of ozone production with dry air flow. The following parameters were fixed: $t_r = 0.5$ s; $t_a = 80$ s; $V = 20.019$ kV; and $f = 1$ kHz.

The HV bias, whose value was calculated theoretically, is applied according to a specific time program in order to optimize energetically the whole process. This is achieved by the HV supply described here.

An experimental system has been described and tested and its functional parameters have been optimized. Its performance was found to be superior compared with that of a classical system in terms of smaller power consumption per gram of ozone produced and greater ozone production per electrode area.

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