High voltage waveform influence on ozonizer productivity on dielectric barrier discharge basis

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Abstract. Influence of the high voltage waveform on productivity of a plasma-chemical ozone generator on the basis of dielectric barrier discharge (DBD) is studied. Experimental studies were carried out using of two types of AC high voltage: at first, AC high voltage (the voltage effective value is equal to $U_2=11$ kV), representing continuous periodically repeating inharmonic structures with frequency $f_2=400$ Hz; secondly, pulsed high voltage with the amplitude equal to $U_p=20$ kV, pulse width 50 ns, the pulse edge 20 ns and the pulse duration 2.5 ms (thus, the pulse repetition rate, in average, is equal to 400 Hz). For the second case, the productivity by ozone of the DBD cell is significantly higher.

1. Introduction
A large number of factors influence on the effectiveness of a plasma-chemical ozone generator based on a dielectric barrier discharge (DBD). Thus, in papers [1, 2] it is shown that the shape of DBD cell electrodes affects significantly on the ozone generation. In paper [3] a new solid-state bipolar multilevel high-voltage pulse generator was proposed to study influence of the rising and falling edges, as well as the forms of high-voltage pulses. Effect of frequency and magnitude of the voltage applied to the DBD cell electrodes is studied in paper [4]. In paper [5] effect of a diamond layer deposited on an active electrode in DBD cell on electrical characteristics and ozone production in air is studied. It is found that, in this case, ozone concentration in the discharge cell and ozone yield increase. The experimental and numerical results, presented in paper [6], show that the shorter high-voltage pulses applied to the DBD cell electrodes lead to increase in ozone production. The dependence of synthesized ozone amount on the polarity of high-voltage applied to the DBD cell electrodes is studied in papers [7, 8]. The effectiveness of using of various materials in plasma-chemical ozone generators as a dielectric barrier or surface films, deposited on a dielectric, is investigated in papers [9-11]. In paper [12] dependence of productivity of plasma-chemical ozone generator, operating on DBD, on the value of electrodes active electrical resistance is studied.

In this paper the productivity dependence of plasma-chemical ozone generator on the shape of high-voltage pulses, applied to the electrodes of DBD cell, is studied.

2. Experimental setups and results analysis
Experiments were performed with DBD cell with plane-parallel electrodes (figure 1). DBD cell is a rectangular sealed parallelepiped, in which in the following order a metal electrode (aluminum) – an air gap – a dielectric (glass-bonded (reinforced) dielectric material) – a metal electrode (copper foil applied to the dielectric surface) are placed parallel to each other. The pressure in the cell is equal to atmospheric,
and the temperature is 21°C. The surface area of each of the square electrodes is 49 cm², the dielectric thickness is 1 mm, the distance between the aluminum electrode and the dielectric (air gap) is 3 mm. Connections (fittings) are installed on the sides of the discharge cell. Pumping 1.5 liters of air per minute compressor is connected to one fitting. An ozonometer with a measuring range of ozone concentration from 1 to 30 mg / L at an absolute pressure from 90 to 200 kPa is connected to the second fitting to measure of ozone concentration in the air flow.

The electrical circuit for the discharge cell connection to a voltage source with an effective value $U_{in}=220$ V and frequency $f_1=50$ Hz is shown in figure 2. The voltage oscillogram at the output of the electromechanical frequency converter (EFC) is shown in figure 3. In EFC output effective voltage value is equal to $U_1=110$ V. As seen in figure 3, the EFC receives a harmonic signal with a frequency $f_1=50$ Hz, but this signal in the its output is distorted and is not harmonic. At the same time, a periodically repeating inharmonic structure with frequency $f_2=400$ Hz is visible on the voltage oscillogram (see figure 3). The voltage effective value at the output of the single-phase transformer (element 4 in figure 2) and that is applied to the DBR cell electrodes is equal to $U_2=11$ kV.

![Figure 1. The DBD cell.](image)

![Figure 2. Electrical scheme of the DBD cell connection. Here 1 is the auto-transformer; 2 is the electromechanical frequency converter for increase the voltage frequency from $f_1$ to $f_2$; 3 is the watt-meter; 4 is the single-phase transformer with transformation ratio 100:10000 of low voltage to high voltage (full power is equal to 640 VA); 5 is the kilovoltmeter; 6 is the oscilloscope.](image)

Under the above conditions the synthesized ozone amount at the outlet of the discharge cell was measured experimentally. After applying the high voltage to the DBD cell electrodes, ozone concentration increased within 10 seconds to a maximum constant level of 3.6 mg / L. Then, ozone concentration decreased, and after 1 minute after the experiment start, the ozonometer stopped recording ozone. Dielectric breakdown occurred, on average, 2 minutes 32 seconds after the high voltage was applied to the electrodes.
Then the experiment was carried out using a pulsed high voltage source (PHVS) [13, 14] applied to the DBD cell electrodes (figure 4). PHVS is connected to an electrical network with effective voltage value $U_{in}=220$ V and frequency $f_1=50$ Hz. The voltage pulse amplitude is equal to $U_p=20$ kV. The pulse width is equal to $\tau_w=50$ ns and the pulse edge is equal to $\tau_e=20$ ns. The pulse duration is equal to $\tau_p=2.5$ ms (thus, the pulse repetition rate, in average, is equal to 400 Hz).

![Figure 4. Experimental setup with a pulsed high-voltage source.](image)

For the above parameters of high voltages in the two considered cases, the powers applied to the DBD cell are respectively proportional to the values

$$U_2^2 \quad \text{and} \quad \frac{U_p^2}{\tau_p} \left( \tau_w + \frac{\tau_e}{2} \right).$$

Here it is assumed, that in the second case the high voltage pulse is rectangular and its duration is equal to $(\tau_w + \tau_e)/2 = 60$ ns. Thus, ratio of the powers, applied to the DBD cell in the first and second cases is equal to

$$\frac{U_2^2 \tau_p}{U_p^2 \left( \tau_w + \frac{\tau_e}{2} \right)} = \frac{121 \cdot 2.5 \cdot 10^{-3}}{400 \cdot 6 \cdot 10^{-8}} = 1.26 \cdot 10^4.$$

Dynamics of changes in ozone concentration in time from the moment a pulsed high voltage voltage was applied to the discharge cell electrodes is presented in table 1. The discharge cell breakdown occurred, on average, 2 minutes 57 seconds after the high-voltage pulse voltage was applied to the electrodes.

Table 1. Ozone concentration dependence in time.

| Time (s) | Ozone concentration (mg / L) |
|----------|-----------------------------|
| 10       | 4.9                         |
| 20       | 6.8                         |
| 30       | 8.1                         |
| 40       | 9.9                         |
| 50       | 9.24                        |
| 60       | 9.24                        |
3. Conclusion
Thus, the shape of high-voltage significantly affects the performance of the DBD-based ozonizer. Use of short (on the order of several 10 ns) high-voltage pulses can provide a higher performance of the DBD-based ozonizer than a continuously varying AC high voltage at the same high-voltage waveform repetition rates in the cases under consideration. One of the factors providing a higher productivity of the ozonizer in case of use of short high voltage pulses is that the DBD cell is heated to a lesser extent.

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