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Analysis of the process of ozone generation and micro-channel intensity distribution by the discharge analysis method

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Growing range of ozone application followed by the increase of its production makes the problem of optimization of the process of ozone synthesis very significant from the viewpoint of energy consumption. Ozone, using silent discharge method, is mostly generated in the micro-discharge, however the other micro-channel also decomposes it. In order to take advantage of the whole discharge area, the micro-discharges should be distributed as uniformly as possible. Conventional energy sources use coal or oil as fuel. In some cases, it is not possible to reach power lines. From the other point of view, application of traditional power sources causes pollution of environment. To get the ozone generation process as clean as possible and also effective, a plate ozonizer with PV modules was used.

Key words: *ozone generation; silent discharge; solar energy*

1. Introduction

Ozone generators are chemical reactors identified mainly as heat exchangers. The efficiencies for the generation process alone do not exceed 20% at optimal conditions with oxygen as feed gas. Ozone formation is a two-step reaction, which starts with the dissociation of O_2 molecules by the electrons in a micro-discharge:

$$e + O_2 \xrightarrow{k_1} 2O + e \qquad (1)$$

The second step describes a three-body reaction:

$$O + O_2 + M \xrightarrow{k_2} O_3 + M \qquad (2)$$

where M is a third collision partner which could be atoms of O, molecules of O_2 or O_3.

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It seems that one of possible ways to increase the efficiency of synthesis of ozone is to apply an electrode rotation system to the ozonizer. It is known that such a system has a positive effect on the ozone generation process [1–3].

The main feature of silent discharge is that the presence of dielectrics leads to the formation of a large number of micro-discharges. Ozone is mostly generated in the micro-discharge, however the other micro-channel also decomposes it. After O_3 formation, the region of ozone concentration has the same geometrical distribution as the atomic oxygen concentration that is the micro-discharge volume of about $r = 100$ μm radius. From that region, ozone diffuses to the background with the time $\tau \approx 1.6$ ms.

$$\tau \approx \frac{\pi r^2}{D} \tag{3}$$

The diffusion coefficient of O_3 in O_2 equals $D \approx 0.2$ cm^2·s^{-1}. Applying electrode rotation we can speed up the slowest (see Eq. (3)), third phase of the ozone generation process – ozone diffusion into background. In order to take advantage of the whole discharge area, the micro-discharges should be as far as possible uniformly distributed [4]. We presume that with the electrode rotation we can influence the discharge, bringing it into a more homogeneous form. Described later research employing the method of discharge analysis shows that with higher electrode rotational speed the discharge does become more uniform.

2. Experimental

2.1. Construction of the ozonizer

The main ozonizer system (Fig. 1) consists of an enclosed chamber (later referred to as housing), electrodes, dielectrics and connecting elements. In the presented setup, electrode cooling systems as well as gas cooling systems were not used. Each of the above-mentioned systems was enclosed using the polyacrylate housing. The housing can be separated into two parts, each one with a diameter of 150 mm and the thickness of about 50 mm. The parts of the housing were connected by eight holding down bolts. The electrode system was placed inside the ozonizer body. This system can be partitioned into two electrodes and one dielectrics layer. In the presented part of the research, a glass plate with the thickness of 0.75 mm and the diameter of 80 mm covers the grounded electrode. The upper, high voltage electrode was also used as a part of the gas supply subsystem. In this electrodes configuration, the discharge activity area equals to 1.94×10^3 mm^2. The synthesis gas was brought into the ozonizer centrally through the electrode and four pipes located outside the electrode carried out the product. The research into the parameters of the ozonizer with the rotating electrode required variable discharge gap spacing. The construction of the high voltage electrode made this possible. The variation in gap spacing ranges from 0.5 mm to 3 mm.

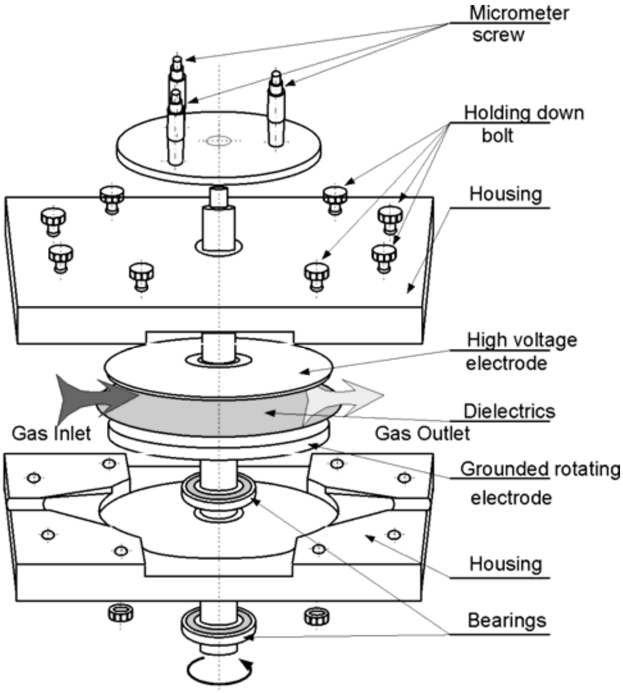


Fig. 1. The main ozonizer diagram

A solar system was used as a power supplying subsystem. The hybrid solar-thermal system (Fig. 2) consisting of 20 photocollectors of "Hevalex" KS 2000 S type and 16 photomodules of "Solara" SM 400 S type was installed on the roof of the Department of Management and Fundamentals of Technology (Lublin University of Technology, Lublin, Poland). A general purpose of the operating system was to provide the thermal system of the department buildings with the electricity generated in PV modules, as well as to ensure the regressive circulation of working liquid in photocollectors, which results in the stabilization of the operating conditions of the solar cell.

Fig. 2. Solar system installed on the roof of the assembly hall of Lublin University of Technology

PV modules can capture more light if they are adapted to rotate around either North-South (NS) or East-West (EW) axes. Rotation around the EW axis allows the module to compensate the changes of the seasonal sun altitude, while rotation around the NS direction makes it possible to align the module with the daily sun movement. That capability of rotation of the PV modules was achieved by a solar tracking system administered by the PC and powered also by the electricity from the PV modules. This “following-the-sun” system ensures that the flat solar module is faced to the sun for all the time and, consequently, the amount of solar irradiation reaching its surface is increased in comparison with the stationary module.

2.3. Discharge photography method

The setup shown in Figure 3 was assembled in order to get more information about discharges during ozone generation in the rotating electrode ozonizer system. This system was based on the Lichtenberg discharge photographic method. In our setup, a photographic plate was replaced by a photographic paper.

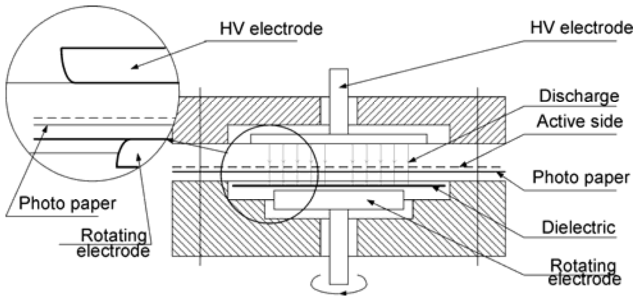


Fig. 3. Scheme of the discharge photography method

Figure 3 shows how the paper was connected to the ozonizer body. Such a placement allowed investigating the influence of the electrode rotation on the discharge conditions. In the other case, when the paper was placed directly on the dielectric, the conditions of gas flow were examined. The paper was sensitive to white light, which enabled recording the light emitted by excited molecules of gas. As a matter of fact, the sensitivity of the paper was lower than that of the photographic plate. The time of the paper exposition was longer and ranged from 2 s to 0.5 s. The time of exposition mainly depended on the kind of gas. The clearest photos were obtained when the exposition times were 2 and 0.5 sec in oxygen and air, respectively. It results from the exposition times that the light emitted by nitrogen was several times more intensive than that emitted by oxygen.

3. Results and discussion

Because of a large number of analyzed photographs, the traditional methods of their evaluation hardly permitted distinguishing the areas with similar light intensities,

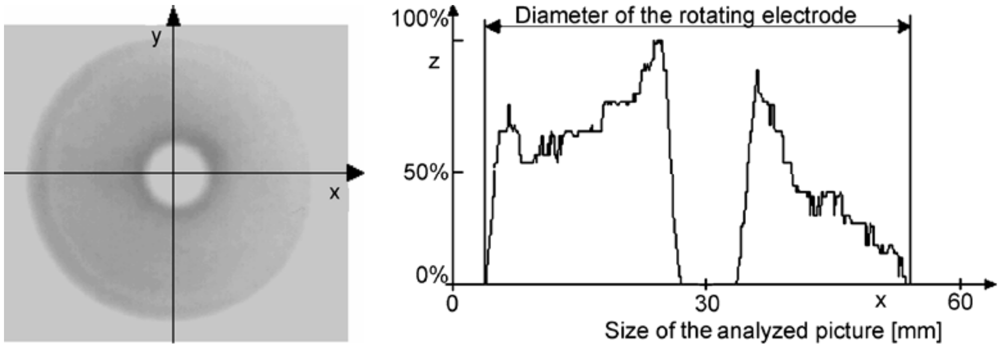
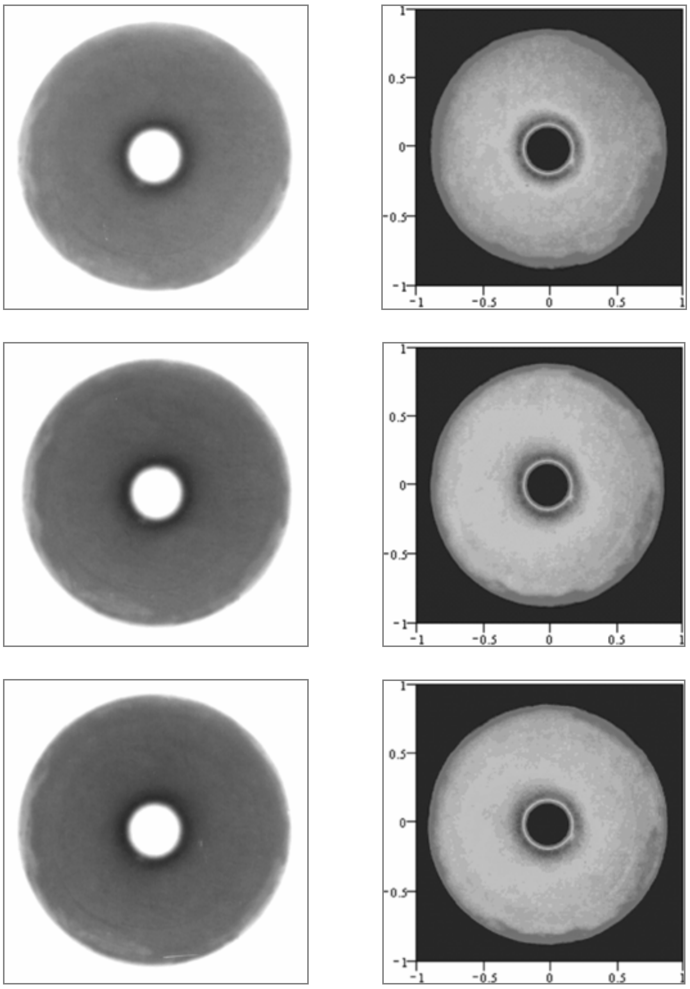


Fig. 4. Discharge picture with the analysis of discharge intensity



a)

b)

c)

Fig. 5. Discharge photo- and computer analysis. Gas gap – 0.5 mm; gas – oxygen, flow – 1.5 dm^3/min, voltage – 9.0 kV, dielectric – glass (0.75 mm), rotational speed: a) 0 rpm, b) 1200 rpm; c) 1600 rpm

therefore, the developed pictures were exposed to a computer scanning (Fig. 4). As a result, a number of colour graphs (presented here as black-white prints) of scanned pictures were obtained, examples of which are shown in Fig. 5. In Figure 5, a collection of black points represents the areas with no discharge. Gray scale changes from gray to white, corresponding to areas containing from a low (gray) to a very high (white) intensity of discharge. Comparing the images of discharge obtained under similar conditions (the electrode rotational speed was the only variable) some differences between them could be observed. In the case of the rotating electrode, almost the whole electrode area (the electrode outer edge shown as a light circle) was covered by discharge. In some areas discharge was weak or even not observed. The filling of electrode area by discharges was closely related to rotational speed. The homogeneity of the discharges increased with the rotational speed. In the case of a non-rotating electrode, the area of discharge was smaller than that of the electrode. Comparing these cases (rotating and non-rotating) it can be said that the discharge volume was utilized more effectively when the rotating electrode was used.

4. Conclusions

The efficiency of ozone generation in the rotating-electrode ozonizer with rotation 1200 rpm was about 20% higher than that without rotation at oxygen gas flow of 3.0 dm^3/min (Fig. 6).

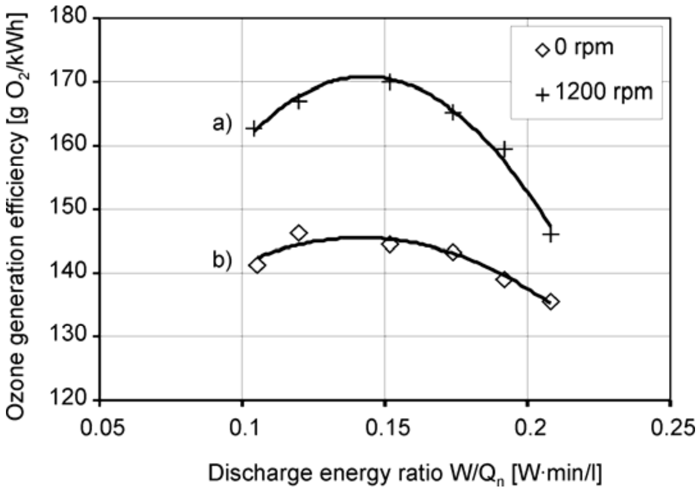


Fig. 6. Ozone generation efficiency for various electrode rotational speeds vs. discharge energy ratio: a) setup 1, gas gap: 1.5 mm, flow: 1.5 dm^3/min b) setup 2, gas gap: 3.0 mm, gas flow rate: 3.0 dm^3/min

No effect of electrode rotation on average discharge power was observed. Average discharge current was not significantly affected by the electrode rotation. Ozone generation efficiency significantly depends on the discharge gap spacing and increases in the narrow gap distance.

Acknowledgements

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