Ozone generation from two hollow needles to plate electrical discharges enhanced by an airflow

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Abstract

The efficient ozone generation plays an important role from the standpoint of many applications. Most of the ozone produced is with the help of electrical discharges, e.g. DC, AC or pulse corona discharge or dielectric barrier discharge. In this paper we studied ozone generation by two hollow needles to plate DC electrical discharge enhanced by the airflow through the needle electrodes. We present the results concerning production of ozone versus discharge current for the discharge between one or the second needle to plate electrodes or between two needles to plate discharge for needles to plate distances ranging from 4 to 6 mm. The power delivered to the discharge for different inter-electrode configurations was also determined. It was found that for increasing needles to plate distance the production of ozone decreases. The experiments were performed for the needles biased negatively.

1. Introduction

The efficient ozone generation plays an important role from the standpoint of many applications, e.g. treatment of the drinking water, sterilization of medical instruments, restoration of buildings after fire and floods etc. The ozone for these applications is produced by electrical discharges. Main electrical discharge, which can be used for the above mentioned purposes is a dielectric barrier discharge and a DC or AC corona discharge. The corona discharge involves different electrode configurations. One of these is a needle to plate or multi-needle to plate electrode configuration.

The experimental investigation of multi-point corona discharge devices for direct ozonization of liquids was performed in [1]. Electrical parameters of different types of multi-corona discharge reactors and production of ozone for the flow of air or oxygen through the discharge chamber is studied in [2,3].

However in all these papers the discharge is enhanced by a flow of gas around the needle electrodes. We have however proposed in [4] hollow needle-to-plate electrode configuration in which the feeding gas is supplied into the discharge volume through the needles. The advantage of this arrangement is that all the gas passes through the discharge volume and therefore is affected by plasma chemical processes.

In this paper we present the results of study of ozone generation from two hollow needles to plate electrical discharges for different distances between the tips of the needles and a plate electrode. As far as this type of the discharge with needle biased negatively is more efficient source of ozone than the discharge with the needle biased positively [4] the presented experiments were performed only with the needles biased negatively.

2. Experimental arrangement

The experimental arrangement for the study of the ozone generation from two hollow needles to plate electrical discharges enhanced by airflow is shown in Figure 1. The electrode system was situated in the circular glass discharge tube of the inner diameter 38 mm. It consisted from two hollow stainless steel needles LN (left needle) and RN (right needle) situated perpendicular to the plane cap of the metallic cylinder. The needles were used as cathodes and the cylinder as an anode. The distance *d* between the tip of the needles and the plane was adjusted to 4, 4.85 or 6 mm. The needles of the outer diameter 1.2 mm and inner diameter 0.7 mm had sharpened tip at the angle 15°, see Figure 2. The metallic cylinder had a diameter 34.5 mm and a thickness 6 mm. The distance *s* between needles was 9.8 mm.

The experiments were carried out with the ambient air that was supplied into the needles through water and oil separator WOS by a compressor. The airflow through each needle 5 slm was adjusted by a mass flow controller MFC Bronkhorst. The thermocouple TC and the sensor of relative humidity RH measured the temperature and relative humidity in the discharge tube.

Regulated DC power supply provided voltage up to 30 kV. Each needle was ballasted by a resistors $R = 6.17$ MΩ.

The ozone concentration was monitored by API 450 (Advanced Pollution Instrumentation) non-dispersive UV photometric analyzer, which uses mercury line 254 nm as the light source for the absorption and selective MnO_2 ozone scrubber that minimizes the influence of other potential absorbers. The measuring range of the analyzer is 0-1000 ppm.

The experiments were performed either with separate discharge on the left or on the right needle or for the simultaneous discharges on both needles. For this purpose the air inlets to the needles were provided with valves RV_L and RV_R for left and right needle respectively and the electrical circuits of the needles contained switches S_{LN} and S_{RN}.

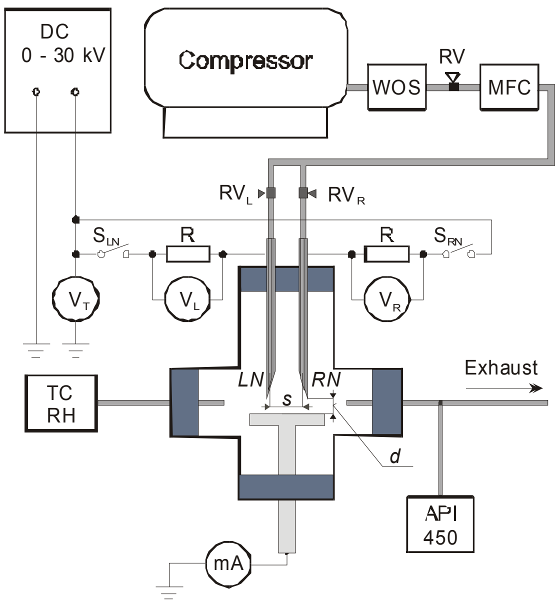

Fig. 1. Experimental arrangement

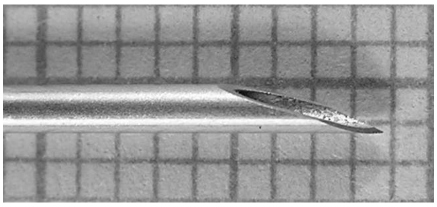

Fig. 2. The tip of the needle electrode

3. Experimental results

The experiments were performed for the needles biased negatively, the airflow through each needle Q = 5 slm and for the distance between the tips of the needles and the plate electrode d = 4, 4.85 and 6 mm. The relative humidity of the feeding air was 18 %. The experimental results are shown in Figure 3 till Figure 7. The polynomial regression of the second order was used to fit the experimental data.

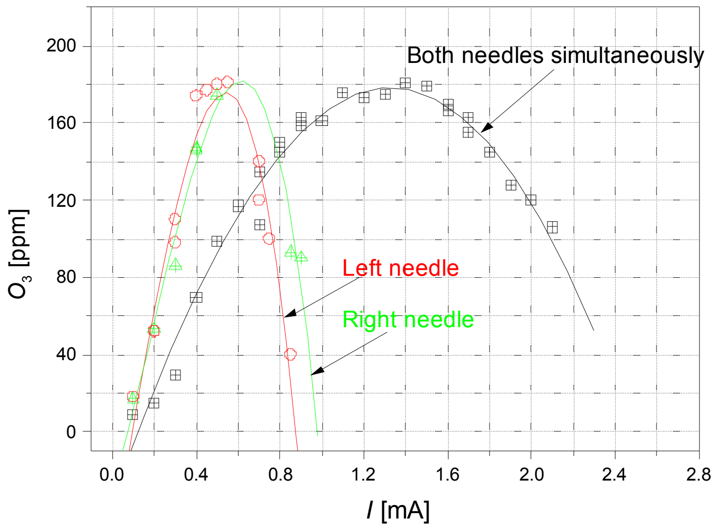

Fig. 3. Concentration of ozone versus discharge current for discharges with individual and simultaneous both needles operation, d = 4 mm, Q = 5 slm per one needle

The concentration of ozone versus discharge current for discharges with individual and simultaneous both needles operation for the distance between the tips of the needles and the plate d = 4 mm and for the airflowrate through each needle Q = 5 slm is shown in Figure 3. From this figure it is seen that the maximum ozone concentration produced by the discharge between the separate needles is the same as the maximum ozone concentration produced by the discharge with simultaneous operation of both needles. In this figure it can be also seen a small shift in the value of current in which maximum ozone production is obtained for the discharges between the left or right needles and plate electrode. This effect can be explained by a fact that the distance between the tip of the left and right needles and the plate is not exactly the same. Due to the fact that the inter-electrode distance d is relatively small then even a small variation of this distance can cause the difference in ozone generation.

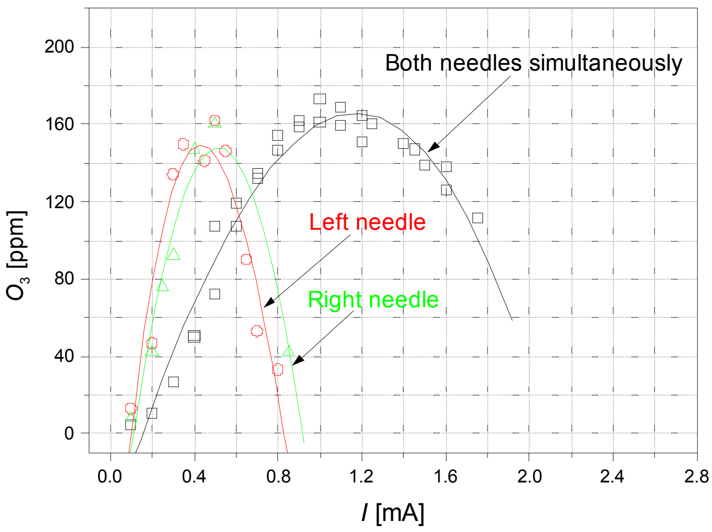

Fig. 4. Concentration of ozone versus discharge current for discharges with individual and simultaneous both needles operation, d = 4.85 mm, Q = 5 slm per one needle

The concentration of ozone versus discharge current for discharges with individual and simultaneous both needles operation for the distance between the tips of the needles and the plate *d* = 4.85 mm and for the airflowrate through each needle *Q* = 5 slm is shown in Figure 4. From this figure it is seen that the maximum ozone concentration produced by the discharge with simultaneous operation of both needles is about 15 ppm higher than the maximum ozone concentration produced by the separate discharge between the left or the right needle to plate electrodes. Similarly as in the case of the distance *d* we can also seen a small shift in the value of current in which maximum ozone production is obtained for the discharges between the left or right needles and plate electrode.

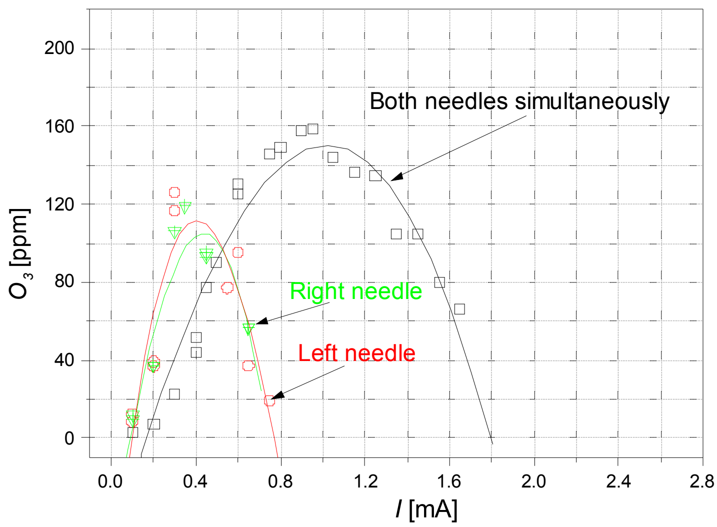

Fig. 5. Concentration of ozone versus discharge current for discharges with individual and simultaneous both needles operation, d = 6 mm, Q = 5 slm per one needle

The concentration of ozone versus discharge current for discharges with individual and simultaneous both needles operation for the distance between the tips of the needles and the plate *d* = 6 mm and for the airflowrate through each needle *Q* = 5 slm is shown in Figure 5. From this figure it is seen that the maximum ozone concentration produced by the discharge with simultaneous operation of both needles is about 40 ppm higher than the maximum ozone concentration produced by the separate discharge between the left or the right needle to plate electrodes.

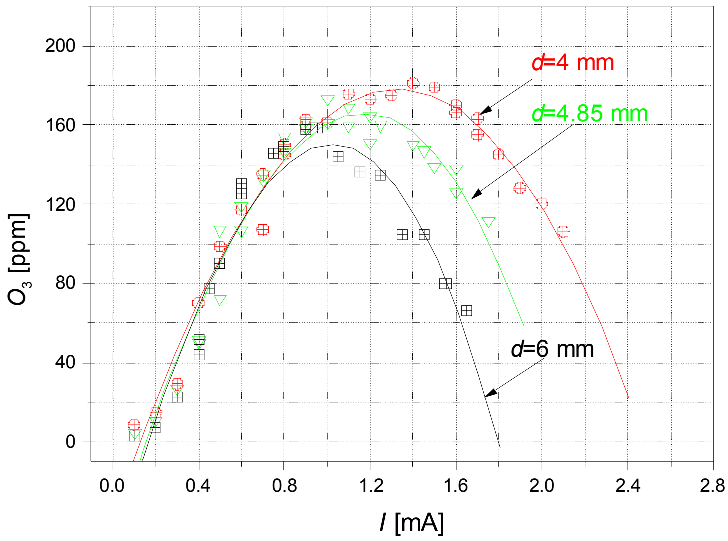

Fig. 6. Concentration of ozone versus discharge current for discharges with simultaneous both needles operation, for different distances d between the tips of the needles and plate electrode, Q = 5 slm per one needle

The concentration of ozone versus discharge current for discharges with simultaneous both needles operation, for different distances *d* between the tips of the needles and plate electrode, *Q* = 5 slm per one needle is shown in Figure 6. From this figure it is seen that with increasing inter-electrode distance *d* the maximum ozone concentration as well as the current for which this maximum ozone concentration is reached decrease.

The power delivered to the discharge versus discharge current for discharges with simultaneous both needles operation and for different distances *d* between the tips of the needles and plate electrode, *Q* = 5 slm per one needle is shown in Figure 7. From this figure it is seen that for particular current with the increasing inter-electrode distance *d* the power delivered to the discharge also increases.

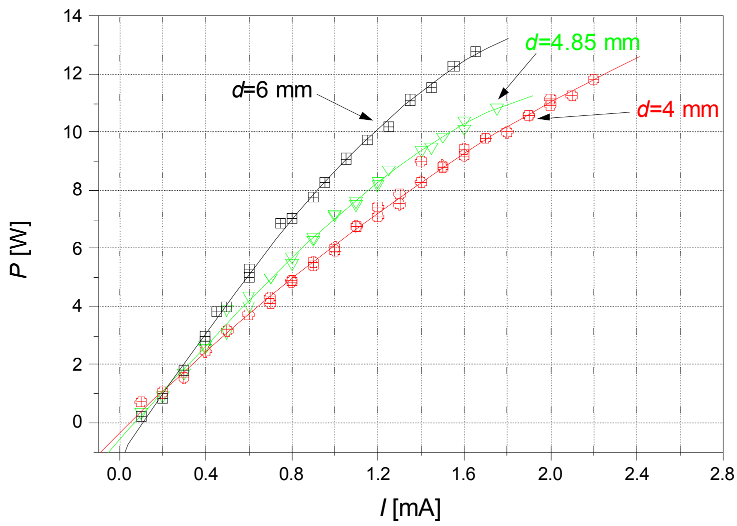

Fig. 7. Power delivered to the discharge versus discharge current for discharges with simultaneous both needles operation and for different distances d between the tips of the needles and plate electrode, Q = 5 slm per one needle

4. Discussion

Results from Figures 3, 4 and 5 show that with increasing inter-electrode distance *d* the difference in maximum ozone concentration for the separate discharges and for the discharge with simultaneous operation of both needles increases. Thus for the inter-electrode distance *d* = 4 mm the ozone concentration by discharges on separate needles are the same as the maximum ozone concentration for discharges with simultaneous both needles operation. For the inter-electrode distance *d* = 4.85 mm the maximum ozone concentration for the discharge with simultaneous operation of the needles exceeds by 15 ppm the maximum ozone concentration for the separate discharges. For the inter-electrode distance *d* = 6 mm difference in concentration is about 40 ppm. This result can be probably explained by the synergetic effect of both discharges on ozone production. Taking into account that the distance between two needles is 9.8 mm then for the case of small distance between the tips of the needles and the plate (*d* = 4 mm) we have two more over independent discharges, which do not influence each other. On the other hand for the inter-electrode distance *d* = 6 mm the distance between the needles *s* and the distance *d* become comparable. The distribution of the electric field around one needle is thus affected by the proximity of the second needle, which influences the reduced electric field *E/N*. As far as the reaction rates of electron impact dissociation processes are the function of the *E/N* the amount of oxygen atoms produced is affected. These oxygen atoms are starting particles for creation of ozone.

As it is seen in Figure 6 the maximum ozone concentration for discharges with simultaneous both needles operation for particular distance *d* between the tips of the needles and the plate electrode decreases from a certain current (exceeding approximately 0.8 mA) with increasing distance *d*. This effect should be explained with the help of Figure 7 from which it is seen that with increasing distance *d* between the needles tips and the plate electrode for a constant current and airflow through the needles the power delivered to the discharge increases. Consequently the amount of dissipated heat also increases, the temperature in the discharge region increases and the ozone destruction processes are enhanced.

This increase of temperature can also explain the decrease of ozone production yield with increasing distance *d* between the tips of the needles and the plate. This effect was observed for both situations that are for separate discharges between one or the second needle and a plate as well as for the discharge on both needles and the plate electrode.

Ozone production yield [g/kWh]		
d [mm]	Discharge between left or right needle and a plate	Discharge between both needles simultaneously and a plate
4	29	29
4.85	26	27
6	16	21

Table 1. Ozone production yield. Airflow through each needle Q = 5 slm.

From the presented table it is seen that for the inter-electrode distance *d* = 6 mm the ozone production yield is higher for two needles to plate discharge than for the single needle to plate discharge. For smaller inter-electrode distances (*d* = 4 and 4.85 mm) there is no significant difference in ozone production yield for single needle to plate and two needles to plate discharge operation.

5. Conclusion

The production of ozone was studied for a DC gas flow enhanced two hollow needles to plate electrical discharge. It was found that maximum ozone production 180 ppm is obtained for small inter-electrode distances (*d* = 4 mm) and maximum difference 40 ppm in ozone production between the discharge with a single needle to plate electrodes and the discharge with two needles to plate electrodes is obtained for high inter-electrode distance (*d* = 6 mm).

The obtained results can help to the better understanding of the ozone formation processes for the case of this electrode arrangement. This electrode configuration of the discharge can be used as a basic element of plasmachemical reactors.

Acknowledgement

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