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Development of ozone generator by modification of the field distribution

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Development of ozone generator by modification of the field distribution

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Abstract. New methods have been established to enhance the ozone production of the surface discharge arrangement. One method sets the discharge electrode a short distance away from the surface of the dielectric material, whilst another uses a special power supply system resulting in a superimposed discharge. According to the experiments, significant differences have been found in the ozone production capacity of the different arrangements. The characteristics of the electric field distribution of the designs have been calculated using the finite element method for the potential; and the Donor-Cell method for the space charge calculation, and the results have been analysed. A method of analysis has been established for the calculated field characteristics, which provides two index numbers. The reasons are highlighted for the differences in ozone production in relation to the index numbers obtained from the fields' distributions of the different arrangements.

1. Introduction

The overwhelming majority of generated ozone is made by means of electric discharges, so it is particularly important to improve the energy and volume efficiency of the generators ozone production processes. The investigations [1] are focused mainly on the dielectric barrier discharge (DBD). The arrangement of an electrode covered by a dielectric layer results in a DBD ranging from a volume to a surface type discharge. In order to make the development more economical, a model is generally constructed.

A method of analysis has been established for the field distribution, which accelerates the planning process of the instruments using an electric discharge. The analysis of the field distribution yields two index numbers. This study attempts to identify the relationship between the electric field distribution and the ozone generation capacity by means of finding the dependence of ozone production capacity on these index numbers.

In [2] and [3], the ozone production has been examined using a new electrode arrangement and a novel type voltage supply system; and significant differences have been found.

2. Method of investigation

The general methods to determine the field parameters, including the space charge in the DBD and the electrostatic precipitator (ESP) are basically the same. Firstly, the *Laplace-Poisson*-equation (1) has to be solved for the scalar potential (φ): finite element, integral equations [4], finite difference etc.

$$-div\ \varepsilon\ grad\ \varphi = \rho\ , \qquad (1)$$

where ρ is the space charge density, ε is the dielectric constant.

Secondly, it is necessary to calculate the space charge distributions and solve the continuity equation; using the characteristics and Donor-Cell methods. The Donor-Cell method [5] is based on the integral form of conservation of charge (the simplified continuity equation; $div\,\boldsymbol{J} = 0$) written for each of the cells that tessellates the solution region. The component of current associated with a given species which crosses an edge of the triangle is approximated in terms of values of the physical parameters at the nodes. An "upstream" difference method is used, whereby charge density at the node outside the triangular is used for edges for current which leaves the triangle. The two equations form an iterative loop.

The power supply voltage used in the experiments is a pulse type voltage, but we can regard it as a constant in our calculation, because the discharge duration is of a maximum of 10 ns; and that is negligible compared to the period of the voltage pulse (0.2 ms).

For the calculation, a two dimensional model was applied. The calculation results in negligible inaccuracy, because the length of the arrangement is many times larger than the width, which results in a simpler calculation procedure than a three dimensional arrangement.

If the conditions for the discharges hold and the streamer starts; it continues on its own. The external conditions do not influence the phenomenon. Consequently at the time of discharge, not only is the peak value of the electric field the significant factor, but the area is also important - as it also has a relatively high electric field as well. Since not only do the conditions of the discharge need to be made stronger (by increasing the field intensity); but the conditions of the discharge have to be realised in a larger place (multiplying the occurrence of the phenomenon).

Two index numbers have been introduced. The first refers to the state before the discharge starts. In this case, we regard the effect of the space charge as negligible. This index number is termed the sum of the discharge field intensity; which subsequently is calculated as the sum of the field intensities that are sufficiently high enough to start the discharge - it is in fact a weighted area measurement. The second index number refers to the state after the discharge. The space charge produced by the discharge relates to the potential distribution which determines the ozone production. Hence, our other index number is the average potential. The effect of the space charge is important and the field calculation includes two methods, which form an iterative loop.

3. Geometry and power supply

Two basically different cases were studied [2, 3]. In the first, the discharge electrode is set a short distance away from the dielectric plate (figure 1). In the second, there are more than two discharge electrodes and a special power supply having two variable pulse drive high voltage outputs was used;

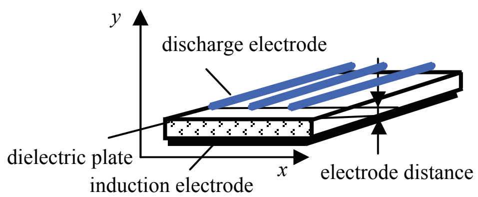

Figure 1 The discharge electrode is set a short distance away from the dielectric plate

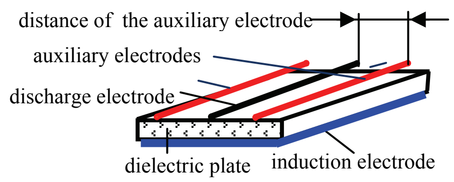

Figure 2 The arrangement of the auxiliary voltage supply

The discharge electrode is connected to one of the high voltage pulses and the other discharge electrode is connected to the ground. The induction electrode is connected to the other high voltage pulse (figure 2). The discharge electrode connected to the high voltage pulse is initialized subsequently as the auxiliary electrode. *(It should be pointed out now that other power supply connection combinations do not produce a stable discharge phenomenon).* The investigation deals with the case where the high voltage pulses have an opposite phase, because it is then that a super-imposed electric discharge can be obtained. Discharges are formed around the discharge and auxiliary electrodes, and they have an opposing voltage pulse. The two different discharges jointly use the charge carriers. In this study, the different constructions that are obtained from the combination of the novel type arrangements have been investigated.

1. All discharge electrodes are set to the surface of the dielectric material and all electrodes are connected to the same high voltage output.
2. All discharge electrodes are set a short distance away from the surface of the dielectric material (figure 1) (the electrode distance is 0.3 mm) and all electrodes are connected to the same high voltage output.
3. All discharge electrodes are set to the surface of the dielectric material and the second discharge electrodes is connected to the ground. The first and third discharge electrodes are connected to the one high voltage output (which is subsequently initialised as the auxiliary electrode). The induction electrode is connected to the other high voltage output (figure 2). The two high voltage outputs are in opposite phase. The distance between the auxiliary and discharge electrodes is 4 mm.
4. The first and the third discharge electrodes (auxiliary electrodes) are set a short distance away from the dielectric material, and the second is set to the surface of the dielectric material. The connection of the electrodes to the power supply is the same as in the configuration shown in figure 2.
5. The discharge and auxiliary electrodes are set a short distance away from the dielectric material and the connection of the electrodes to the power supply is the same as in the configuration shown in figure 2.

4. Results and Discussion

The ozone concentration has been measured [2, 3] using the experimental setup with different electrode arrangements and power supply systems. The results of the experiments show large differences in ozone generation. The high voltage pulse of the power supply was 5 kV in all configurations, and the feed gas was oxygen. In table 1, it can be observed that the new power supply system produces at least five times more ozone then the traditional surface discharge. The setting of the electrodes a short distance away from the surface of the dielectric plate results in ozone production increases in all versions of the electrode arrangements or power supply systems.

Table 1. The ozone production and the index numbers of the different constructions

Configuration	Ozone production [ppm]	Sum of the discharge field intensity [$\cdot 10^7$ V/mm]	Average potential [$\cdot 10^4$ V]
1	750	3.27	3.11
2	950	4.95	3.12
3	5400	9.93	16.20
4	5700	10.90	16.50
5	5900	11.10	16.70

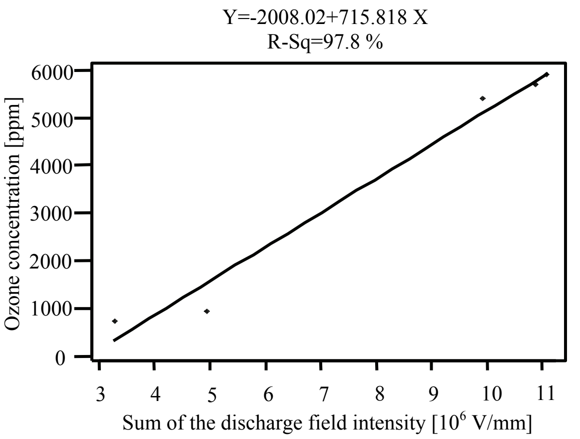

Figure 3. The correlation function of the ozone production and the sum of the discharge field intensity relating to the different configurations

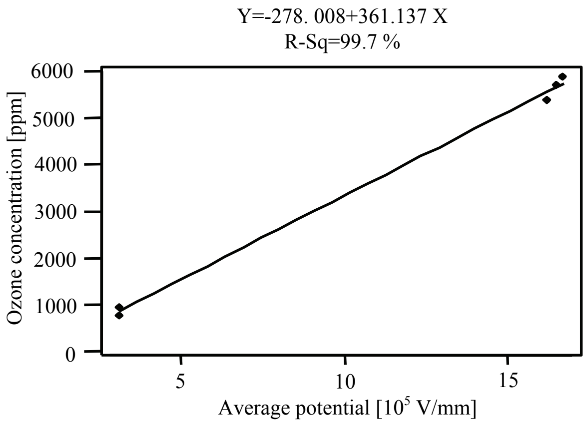

Figure 4. The correlation function of the ozone production and the average potential relating to the different configurations

All the above mentioned configurations were subjected to computer simulation and analysis. The results of the simulation and analysis are also presented in table 1.

Regression has been calculated to highlight the relationship between the ozone production capacity and the index numbers, the relationship between the ozone production and the sum of the discharge field intensity is greater than 97% (figure 3). The relationship between the two variables is supposed to be linear. The relationship between the ozone production and the average potential is also greater then 99%, when the regression is supposed to be linear (figure 4).

5. Conclusion

In this paper, the results prove that the field calculation and the related analysis are suitable for evaluating the ozone production capacity of an electrode arrangement under certain conditions. Firstly, a reference arrangement is necessary to allow a comparison to be made. Secondly, the calculations must be managed under the same boundary conditions and area to get adequate information; and the same calculation method must be applied.

According to the calculation; the change in the electric field and potential distribution are consistently followed by the difference in ozone production capacity, and the regression between the index numbers and the ozone production capacity is greater then 0.97.

The method can be applied in the development of other discharge equipments.

6. References

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