
# Development of an ozone generator by the modification of the field distribution

**PhD theses**

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Budapest, 2006

## Introduction

The increasing demand for ozone makes it necessary to improve the capacity and the efficiency of ozone generators. Ozone is used widely for sterilisation and substituting oxidising materials, and that, directly or indirectly, means hazardous pollution to the environment. A great advantage, besides simple low-cost production, is that there is no side product in the application.

For a long time different chemical materials have been used for sterilisation. Due to a greater awareness of environmental protection, along with more and stricter regulations, the application of other sterilisation technologies is needed. On the basis of the research results activities, the application of ozone makes it possible to solve the major problems.

The development of ozone generators covers three different fields; power supply, electrode arrangement, the materials of the dielectric and the electrodes.

The power supply generates a high voltage for the electrode arrangement to induce an electric discharge. The simplest power supply can be obtained by transforming the line voltage. The introduction of the semiconductors makes possible the wide spread pulse drive power supply, so the weight and size of the instruments are significantly reduced.

Among electrode arrangements, it is classical when there are two parallel plate electrodes and one of them is covered with a dielectric material, whilst in other popular constructions, the electrodes are set to the surface of the dielectric material. The discharge electrode set to one side of dielectric, and the induction electrode is set to the opposite one. The first arrangement produces a volume discharge, and the second generates a surface discharge. Both electrode arrangements produce streamers (small ion channels).

Regarding the applied materials, the first-rate condition is the durability of the electrodes as well as the dielectric material. The other important point is the electron emitting capacity of the material and workability. A very important property of the dielectric material is the dielectric constant, which significantly influences the length of the streamers induced in the electric discharge.

## The target of the researches

The aim of this research was the improvement of the volume and energy efficiency of the ozone generators, namely the efficiency of the present ozone generators at less than 20%. To improve the generation process there are two possibilities; one increases the transformation ratio from oxygen to ozone, the other is the reduction of the decomposition of the generated ozone. So I have

looked for the solution that fulfils the requirements of the above mentioned conditions without increasing the specific energy consumption.

The main field of development is the increase to the active discharge space. Streamers are generated in volume and surface discharges. According to my calculation and measurements, the ozone production significantly depends on the length of the streamers, and that concerns the volume of the active space of the discharge. Regarding enlargement of the discharges, not only is the field intensity of importance, but also the space where the field intensity is sufficiently high to induce discharges.

**Methods and materials**

To lengthen and increase the frequency of the streamers, I have modified the field distribution by varying the settings of the electrodes and the dielectric. Furthermore, I have applied a novel type power supply system. I have made numerical simulations for the new constructions, and have analysed the results. At first I investigated when the discharge electrode of the electrode arrangement of the surface discharge was set a small distance (<1 mm) away from the surface of the dielectric material. Secondly, when there are more than two discharge electrodes and a special power supply is used, which has two variable pulse drive high voltage outputs. The discharge electrode can be 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. The discharge electrode connected to the high voltage pulse is initialized subsequently as the auxiliary electrode. The voltage pulses are in opposite phase.

I have also investigated the ozone production capacity of the different constructions with experiments. The layout of the test equipment makes the variability of the flow rate possible. The reaction chamber is a shielded cylindrical polyethylene tube, which contains the electrode arrangement. The electrical parameters are measured by a digital oscilloscope with a signal recording capacity. The ozone concentration is measured by the equipment, which has been co-developed by the author, and that has been calibrated with the wet chemical method. The investigation includes the measurement of the effect of different physical parameters like pressure, humidity, flow rate, oxygen concentration of the feed gas.

The result of the simulation, and the concerning analysis, has revealed the application of the electrode distance between the discharge electrode and the dielectric plate gives significant difference in the field distribution. Similarly, the application of novel type power supply system results in a large difference in the field distribution compared to the arrangement of simple surface discharge. On the basis of the results of the experiments, relation can be shown between the index numbers of the analysis (sum of discharge field intensity, average

potential) and the ozone production capacity of the arrangements. The investigation also includes the measurement of the specific energy consumption.

## New scientific achievements

### Thesis 1

**I have established a method which uses the finite element method completed with the Donor-Cell method to determine the field distribution. The related analysis appraises the results of the simulation. Using this method, I have shown the relation between the potential and field intensity distribution and between the ozone production capacities of the different electrode arrangement. [1]**

The modelling of the discharge phenomenon is extensively described, and the major part of the literature deals with the discharge process in the electrostatic precipitators. In the construction of the models, account is taken of the many factors which apply to an increasing number of scientific fields.

In both electrostatic precipitators and ozone generators are similar ionisation and gas decomposition processes, due to the electric field induced discharges. To write down static field the *Laplace-Poisson* equation is used. If the space charge is taken into consideration, the simplified continuity equation is applied ($div\,\boldsymbol{J} = 0$). I have determined the field distributions of the different electrode arrangements which takes the effect of the space charge and with negligible the effect of the space charge. When I have taken the effect of space charge in the calculation I have determined the charge distribution with the Donor-Cell method. In taking the effect of the space charge the two methods form an iterative loop, which is convergent to the sum of space charge in the calculation area.

I have analysed the potential and electric field distribution, and that results in two index numbers. One of them concerns the condition preceding the discharge, and the field calculation taking the effect of space charge negligible. The index number is calculated by the summary of the field intensity that is sufficiently high to start the discharge. Really it is a weighted area measurement, and it is initialised as a summary of discharge field intensity. The second one concerns the state after the discharge. The space charge produced by the discharge relates to the potential distribution and that relates to the ozone production also. So, another index number is the average potential and it is generated from the calculation taking the effect of space charge.

The evaluation of the results of the calculations have been shown in the application of electrode distance as well as using the novel type power supply system the area of the high potential and the area of the field intensity increased in comparison to the arrangement of simple surface discharge. The results of the measurements prove, when the index number relating to the arrangement is larger the ozone production is also greater.

**Thesis 2**

**On the basis of the calculations and measurements I have shown, in spite of the electrode arrangement of the traditional surface discharge, that the setting of the discharge electrode a small distance away from the surface of the dielectric increase the ozone production capacity. That improves the volume as well as the energy efficiency of the ozone production. [4,5,6,7]**

In the electrode arrangement of the traditional surface discharge the discharge electrode is set directly to the surface of the dielectric. The discharge is induced beside the discharge electrode on the surface.

When the discharge electrode is set a small discharge away, the discharge can be generated under the discharge electrode. The maximum value of the field intensity decreases but the area of the high field intensity, which is sufficiently high to induce discharge, is larger so that the streamers are more extensive and that results in a more intensive discharge.

I have tested the effectiveness of the method with experiments. The experiments include the measurement of the effect of the different physical parameters (pressure, humidity, oxygen concentration of the feed gas), and effect of electrode distance. I also measured the energy consumption.

On the basis of the measurement it can be stated, setting the discharge electrode a small distance away from the dielectric improves the ozone producing capacity as well as the specific energy consumption of the arrangement. Applying the same voltage and optimal electrode distance the ozone production increases by 10 % using artificial air and the production increases 25 % using oxygen. The specific energy consumption decrease is in the same range as the ozone production increased.

It can also be stated that a certain electrode distance is related to every pulse voltage, which produces the maximum ozone. The increasing humidity and pressure decrease the ozone production more than in the case of the arrangement of a simple surface discharge. The effect of the oxygen concentration in the feed gas has the corresponding effect to the data obtained from the literature. The decreasing oxygen content decreases the ozone production too.

**Thesis 3**

**On the basis of the investigation, I have stated that applying the auxiliary electrode power supply system the ozone production capacity of the ozone generators increases. I have shown the special system including the electrode arrangement and the power supply generate a super-imposed field, which produces a more extensive discharge. [2,3,4]**

The development of the ozone producing facilities, the power supplies and the electrode arrangements have been undertaken almost as independent developments. As the results of the newest research to produce super-imposed discharge needs a pulse work power supply which has two synchronised high voltage outputs. To produce a super-imposed discharge, I have set the electrodes to induce such a field distribution, which lengthens the generated streamers. On the other hand, not only the certainty of the discharge generation has to be increased, but increased in the area which has sufficiently high field intensity to induce discharge.

The super-imposed discharge with the power supply, which was made by me, was my ‘brain child’; and. I have provided with this power supply an electrode arrangement which has three discharge electrodes. The power supply has two independent high voltage pulse drive outputs, and phase difference can be varied between the two outputs. The voltage pulses were in the opposite phase or in a small difference from the opposite phase. There was a stable discharge phenomenon, when one of the high voltage pulses is connected to every second discharge electrode, and the other high voltage pulse is connected to the induction electrode. The remaining discharge electrode is grounded. The discharge electrode connected to the high voltage pulse is initialised subsequently as auxiliary electrodes and the power supply system as auxiliary power supply system.

The investigations have proven that the ozone generation capacity is one and half times higher using artificial air, and five times higher using oxygen than in the simple surface discharge. The specific energy consumption reduces 40 % in both cases. The system works on the same ozone producing capacity when the phase difference is less then +10 or -10 degree, and the larger difference results in a significant decrease in the ozone production independently from the applied feed gas. Both the results of the measurements and simulations prove the distance of the auxiliary electrode and between the discharge electrodes has optima which produces the maximum ozone. The effect of the oxygen content of the feed gas has the same characteristics, as found in the related literature. A decrease in the oxygen concentration of the feed gas results in the ozone producing capacity decreasing also.

**Utilization of the results**

The energy and volume efficiency can be improved by the application of the new electrode arrangements. The instruments I have used to take the measurements were made for the experiments, but a new industrially designed instrument will be constructed in the near future. When the industrially designed prototype works properly, mass production can be started. .

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