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TEMPERATURES IN THE OZONIZER GAP

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Abstract. The calculations of the changes in a gas temperature in a single microdischarge channel were carried out. The changes in a gas velocity profile caused by the microdischarge were determined.

Keywords: ozone synthesis, gas temperature, heat transfer modeling.

INTRODUCTION

The temperature in the ozonizer discharge gap is a parameter affecting to a significant degree the course and final effect of the ozone synthesis process under silent discharge conditions. Temperature is one of the main parameters forming the relative electric field strength value at which the discharge proceeds. The electric field strength influences subsequently the concentration and energy of the electrons in the microdischarge channel. These parameters decide on the kind of the gas molecules exciting, the rate of the both oxygen and ozone dissociation and finally decide on the concentration of atomic oxygen, one of the ozone synthesis process substrates.

The course of the reactions occurring after the discharge to a greater degree depends on temperature. The rate of reactions in which ozone is formed and also those in which ozone is decomposed directly (and to an essential degree) depends on temperature. Especially the possibility of obtaining high ozone concentration depends on temperature [1]. The maximum of ozone concentration results from the obtaining of the stationary state in a system. In such conditions the ozone formation rate is equal to the rate of its destruction.

The temperature level and its topography in the discharge gap are difficult to precisely determine. The distribution of temperature in the discharge gap is an effect of the energy delivered, the localisation of the areas in which the heat is emitted as well as of the intensity and directions of heat removal. The heat exchange coefficient values between the gas in the gap and the cooling surfaces depend on the gas flow character and its physical properties. A system analysis of ozone synthesis in a commercial installation was examined in ref. [2-4].

There are no doubts that the microdischarges modify to a significant degree the gas flow character in the discharge gap. In such a case the conditions in which the gas properties should be considered in the calculations are difficult to univocally determinate. In this paper an attempt to analyse of both the way and the result of the discharge on the gas temperature and its velocity in the gap was undertaken. The analysis concerns the very simplified discharge model limited to a single, insulated microdischarge.

RESULTS AND DISCUSSION

The model

Figure 1 shows the simplified discharge gap and the microdischarge channel. The ozonizer is cooled by a medium of temperature T_c. Before the discharge in the whole gap the temperature T_e prevails and oxygen with the average linear velocity u_e flows. During the discharge energy is emitted in the channel. It was assumed that the energy $E_{ch,}$ is emitted in the discharge channel which is 80% of the energy emitted during the microdischarge. That energy is sufficient to increase the gas temperature from T_e up to T_{ch} in the whole channel volume. It was assumed that 20% of energy is emitted directly on the gap walls, at the base of the microdischarge channel. This part of energy was signed as E_w (Fig. 1). In order to simplify the model it was assumed that only molecular oxygen always exists in the gap. The existence of excited particles and occurrence of chemical reactions was neglected. The temperature in the whole channel volume attains the same value equal T_{ch} directly after the discharge. The gas pressure increases according to the temperature increase in the channel. Subsequently, the gas in the channel volume expands. The matter of the calculations were both the temperature and the gas velocity changes, which are the result of the microdischarge occurrence.

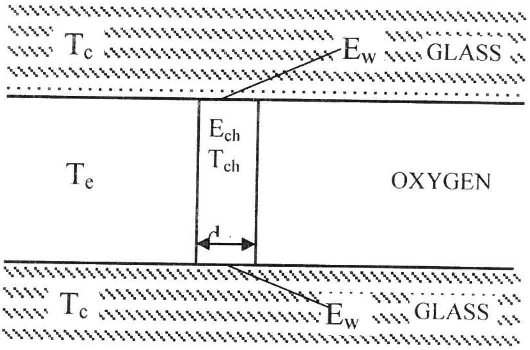

Fig. 1. Discharge gap and single microdischarge model.

In calculations it was assumed that the gap is between the parallel plates with a distance of 1.5 mm. The breakdown voltage assumed was 3 kV. The electric charge transferred during a single discharge was ca. 0.5 nC and the microdischarge channel diameter was 100 μm. The assumed energy of a single microdischarge was $1.6*10^{-6}$ J. The temperature of the cooling medium was assumed as 298 K and the average velocity of the oxygen in the gap was 0.1 m/s (NTP = normal temperature pressure). The value of the microdischarge parameters assumed in the calculations are in accordance with the parameters proposed by other authors [5-10].

The calculations were performed using the program Fluent. Fluent is a state-of-the-art computer program for modelling fluid flow and heat transfer in complex geometries. The calculation procedure consist of the following steps: creation the model geometry and grid, choosing the basic equations to be solved (laminar or turbulent flow, chemical species or reaction, heat transfer models etc.), specifying material properties, specifying the boundary conditions, calculation a solution and examination the obtained results. In the numerical simulation of the ozone synthesis process the momentum and heat differential balance equations have been solved. Oxygen properties have been taken from the Fluent database. The grid consisted of 80,000 cells.

Temperature changes

Figure 2 shows the temperatures calculated for the straight line located along the gap in the half-width. That line is crossing the axis of the microdischarge cylindrical channel. The distance from the centre of the microdischarge channel is presented on the X-axis. The direction of the oxygen flow is from negative to positive values. As can be seen, in the whole channel cross-section the temperature increase resulting from discharge is in that case 100 K. Just after the discharge heat removal to the surrounding starts. The heat is removing by both the gap walls and the microdischarge channel ambient gas. As a result the heat is finally taken away also by the walls of the discharge gap. The following curves in Fig. 2 denote the temperatures in the half of the gap width after the different discharge time. The temperature decrease directly after the discharge is significantly higher than after dozens of microseconds.

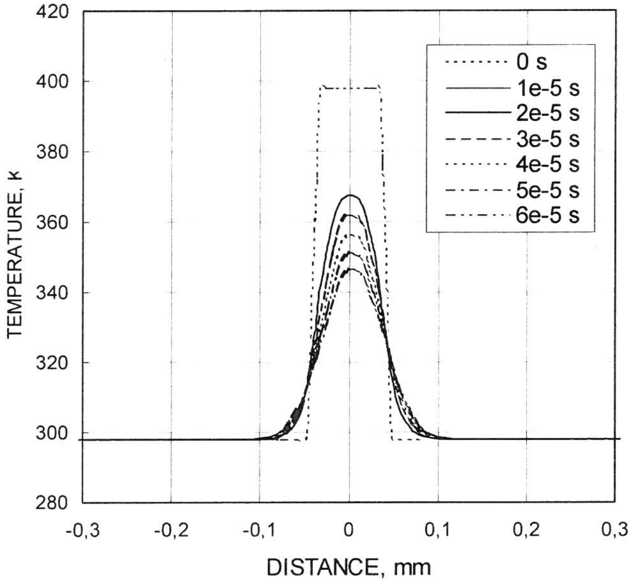

Fig. 2. Temperatures in the microdischarge channel (in a place of the microdischarge occurence) after various periods from the discharge.

For example, 10 μs is sufficient to decrease the temperature from 398 K by 27 K. The decrease in temperature of consecutive 25 K required still 50 μs. Whereas after ca. 1 ms after the discharge the temperature decreases almost up to 300 K. This value is near the temperature in the gap before the discharge. The maximum temperature point is systematically shifted along the gas flow direction and velocity.

Gas velocity

The average oxygen velocity in the discharge gap was 0.1 ms^{-1} (NTP). At this velocity the conditions when no disturbances are generated, in the 1.5 mm width gap oxygen flows laminarly. The velocities in the vertical cross-section of the gap in that situation are presented in Fig. 3. Figure 4 shows the gas velocity along the gap, in the half of its width. The velocity at the intake is equal to the average one.

When the gas flows, the velocity profile is being formed characteristically for the actual average velocity and both the channel size and shape. On the X-axis (Figs. 4 and 5) the distance from the centre of the microdischarge channel is presented.

The gas velocities in the gap half-width, which are shaped as a result of the single microdischarge, are presented in Fig. 5. Figure 5A shows the gas velocities after 10 μs from the discharge. In the model assumed, the first effect of the microdischarge is an increase in temperature in the channel. In the first phase, under constant channel volume, the pressure increases also in that space, in accordance to the temperature increase. In the next phase (the gas expansion), significant disturbance of the gas velocity takes place. Near the channel, on the side of the gas inflow, the velocity decreases up to ca. zero after 10 μs. On the reverse side, however, the gas velocity is few times higher than before the discharge. The effect of the gas rapid expansion from the channel volume is very strong in the close vicinity of the channel. When the distance from the channel decreases the increment of linear velocity is smaller and smaller, but exists even at considerable distance from the discharge site. After subsequent 10 μs (Fig. 5B), in the vicinity of the site occupied by the microdischarge channel, the situation was inverted. The gas was withdrawn again into the space occupied earlier by the microdischarge channel. In consequence, on the side of the gas inflow, the velocity increased more than in the situation of undisturbed gas flow. On the reverse side, near the site of the discharge, the gas velocity decreased. Further, the gas velocity is a little higher than was before the disturbance caused by the discharge. In the course of time the results of disturbance by the discharge decays slowly. The profile of the gas velocity tends to gain shape as before the discharge. Since the single-discharge disturbance of the gas velocity is considerable, a significant difference in the gas flow character when the microdischarges will continuously occur in the whole gap volume should be expected. The frequent and considerable local changes of the gas velocity will intensify both the heat transfer and the gas mixing.

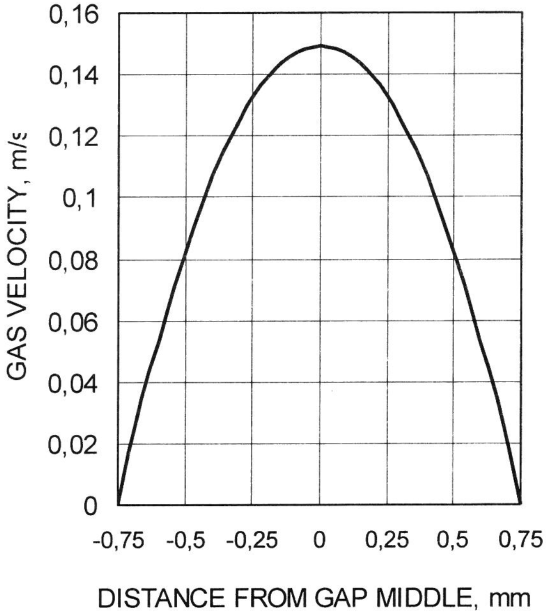

Fig. 3. Gas velocity in a gap cross-section during undisturbed flow.

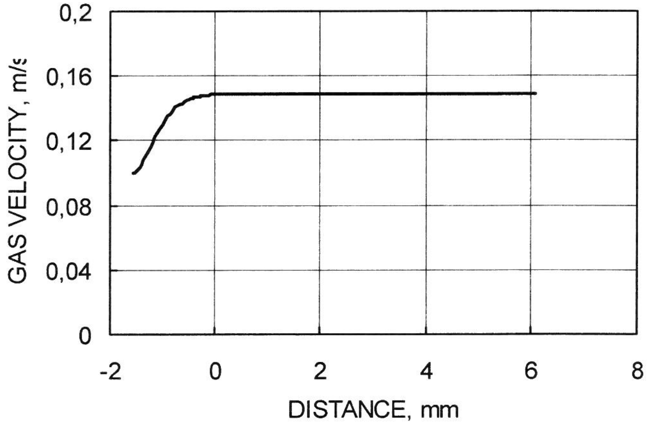

Fig. 4. Gas velocity along the discharge gap in a half-way of the gap width; undisturbed flow.

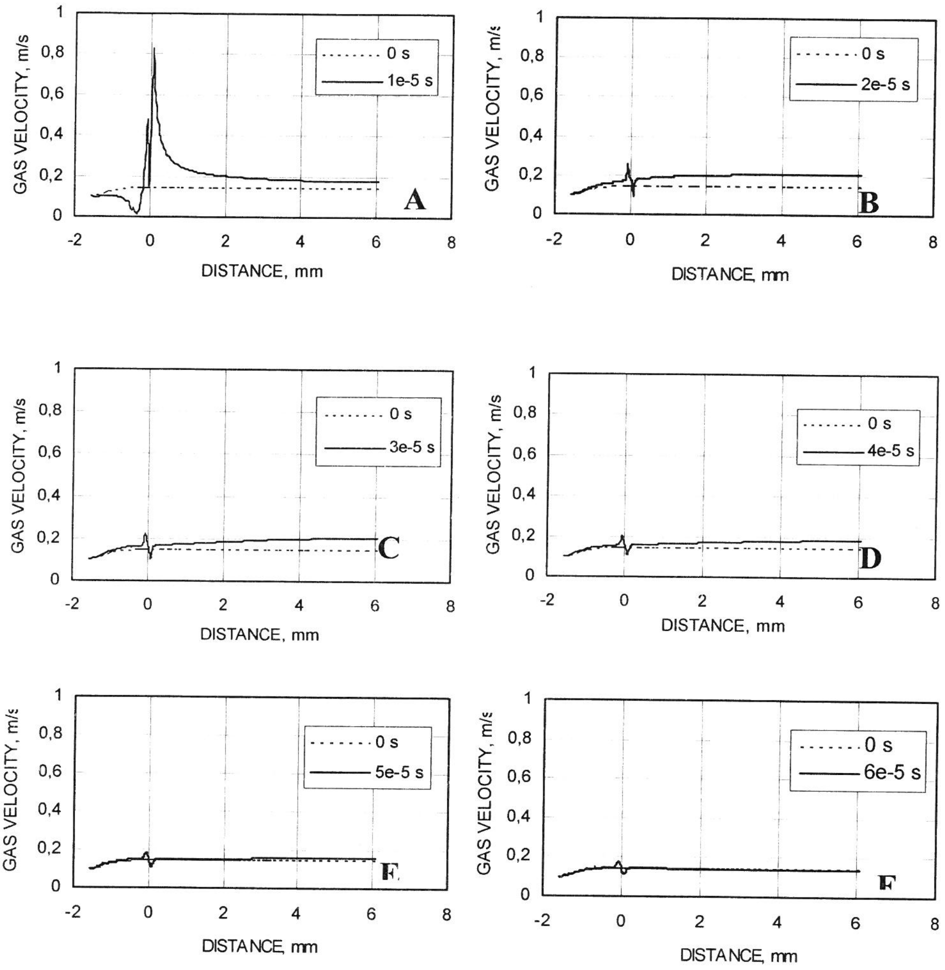

Fig. 5. Gas velocity (in a half-way of the gap width) along the discharge gap after various periods from the microdischarge.

SUMMARY

The analysed model of a single isolated microdischarge is very simplified in comparison with the situation taking place in a real discharge gap. The analysis of that model function gives, however, information permitting to predict the operation of more complicated systems. There is no doubt, that the heat exchange in the discharge gap as well as the heat removed from the gap will be very intensive. This results from the great temperature differences arising in the microdischarge space. The rapid changes of temperature of the particular space fragments cause the local pressure changes as well as the significant local changes of the gas flow direction and velocity. It should be expected that, under discharge conditions, the gas flow character loses its laminar character. The intensive mixing and high-frequent changes of both gas direction and velocity will intensify the heat exchange.

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TEMPERATURY W SZCZELINIE OZONATORA

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Streszczenie. Wykonano obliczenia zmiany temperatury gazu w pojedynczym mikrowyładowaniu. Określono zmiany w profilu szybkości przepływu gazu powodowane przez mikrowyładowanie.

Słowa kluczowe: synteza ozonu, temperatura gazu, modelowanie wymiany ciepła.