THE EFFECT OF JOULE HEATING ON OZONE PRODUCTION IN NEGATIVE CORONA DISCHARGE

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Ozone gas has many industrial applications, such as food sterilization, water purification, gas treatment, etc. [1-4], and it can be easily produced using a variety of electrical discharges. Among them, corona discharge is frequently used in those applications when only moderate ozone concentrations are required. Ozone production in negative corona discharge is strongly affected by the gas heating due to Joule effect. However, this effect has been often ignored in numerical simulations of corona discharge [5-6]. In this work, we present an experimental and numerical investigation of ozone generation using negative corona discharge in a coaxial wire-to-cylinder electrode system. The numerical simulation is based on a hydrodynamics model that combines the physical processes in the corona discharge with the chemistry of ozone formation and destruction in oxygen. The equations governing the problem are the continuity equations for the density of each species and Poisson's equation for the electric field.

The corona discharge reactor used in the experiments consisted of a tungsten wire (the cathode) with radius r = 0.05 mm, situated along the axis of a stainless steel cylinder (the anode) with inner radius R = 0.65, 0.85 or 1.1 cm. Both the wire and the surrounding cylinder were L = 5 cm long. The wire was subjected to negative DC high voltage and the cylinder was connected to the ground. The discharge cell was fed with high purity oxygen (99.995%), and ozone density was determined by means of UV absorption spectroscopy. The corresponding measurements are presented in Fig. 1 as a function of the applied voltage.

Fig. 2 shows the radial distribution of ozone, atomic oxygen and electrons inside the reactor according to the numerical simulation. The fact that atomic oxygen is formed by electron impact dissociation of molecular oxygen,

$$e + O_2 \rightarrow O + O + e,$$

explains the similar radial distributions of electrons and atomic oxygen. This reaction is then

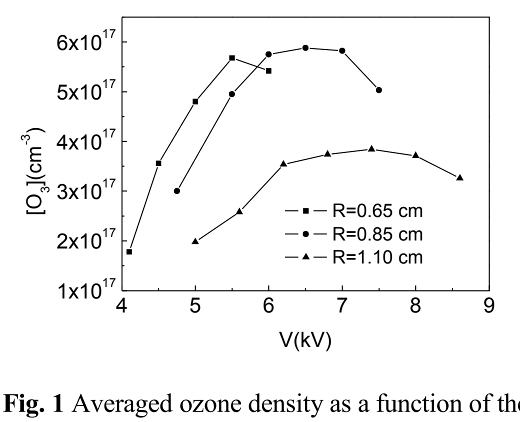

Fig. 1 Averaged ozone density as a function of the applied voltage for three different anode radii.

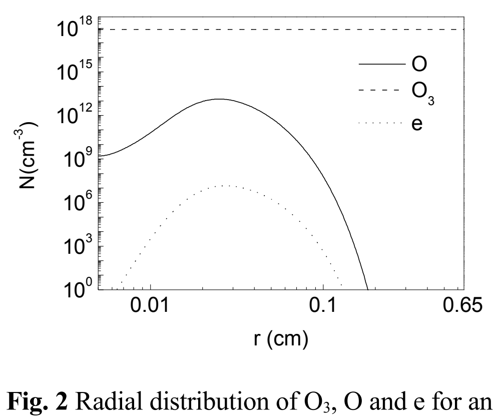

Fig. 2 Radial distribution of O_3, O and e for an applied voltage of 5 kV.

followed by a three-body reaction that produces ozone,

$$O + O_2 + M \rightarrow O_3 + O_2 \ (M = O_3 \text{ or } O_2).$$

The change in the gas temperature due to Joule effect has two consequences on the electrical discharge. Firstly, it changes the gas pressure and, thus, the gas transport coefficients. Secondly, it changes the rate coefficients of many reactions that depend on temperature. The importance of Joule heating can be easily appreciated in Fig. 3, where the radial distribution of temperature corresponding to different applied voltages is presented. Clearly, there is a significant increase of temperature in the vicinity of the wire, where ozone is generated [5]. Therefore, in this region, the destruction of ozone becomes more intense than in the rest of the inter-electrode space, due to the following reactions that are strongly affected by temperature:

$$O_3 + O \rightarrow O_2 + O_2,\ k = 1.8\times10^{-11}\, e^{-2300/T}\ \text{cm}^3/\text{s},$$
$$O + O_2 + O_3 \rightarrow O_3 + O_3,\ k = 1.45\times10^{-34}\, e^{663/T}\ \text{cm}^6/\text{s},$$
$$O_3 + O_2 \rightarrow O + O_2 + O_2,\ k = 7.26\times10^{-10}\, e^{-11400/T}\ \text{cm}^3/\text{s}.$$

The reduction of ozone density at high voltages observed in Fig. 1 is a direct consequence of this effect. Finally, the average temperature is plotted in Fig. 4 as a function of the applied voltage for three different values of the cylinder radius. The larger the anode radius is, the higher the applied voltage must be to observe the same increase of temperature. This is so because the dissipated power depends on the product of the current density and the electric field, and these magnitudes increase with the augmentation of applied voltage and with the reduction of anode radius.

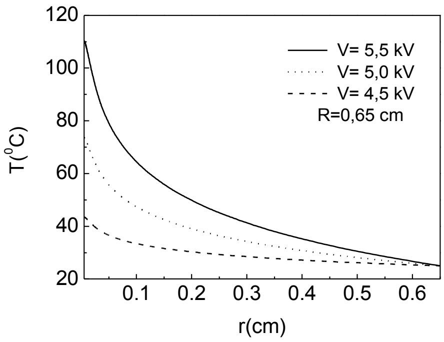

Fig. 3 Radial variation of temperature.

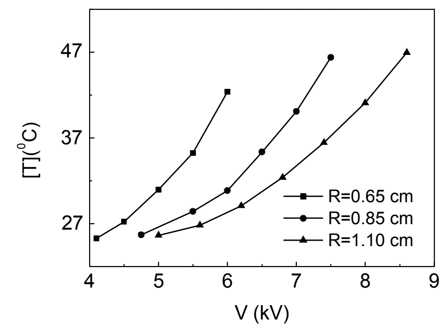

Fig. 4 Variation of the average gas temperature as a function of the applied voltage.

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