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# Corona and back discharges in flue-gas simulating mixture

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ABSTRACT

Results of spectroscopic investigations and current–voltage characteristics of electrical discharges between a needle and plate electrodes in a gas mixture simulating flue gases from coal fired power plants at atmospheric pressure are presented in the paper. In these investigations, back discharge was generated at the plate electrode covered with fly ash layer in order to simulate the conditions similar to those in electrostatic precipitators. To characterize the physical processes in back discharges, the emission spectra were measured and compared with those obtained for normal corona discharge generated in the same electrode configuration but with fly ash removed from the electrode. The emission spectra provide information on elemental and molecular composition of the layer. It was also shown that discharge characteristics in flue gas are quite different from those occurring in ambient air.



## 1. Introduction

The problem of changes in characteristics of electrical discharges when collection electrode is covered with fly ash layer is one of the most important for the collection efficiency of electrostatic precipitators. In specific cases, when fly ash resistivity is sufficiently high, usually larger than $10^{10}$ Ωm [46], the leakage current to the collection electrode is too low, and the electric charge accumulates on the surface and within the layer. When the potential at the surface of the layer deposited on the collection electrode increases to a threshold level the electric breakdown to the layer occurs that significantly changes the pattern of gaseous ions flow between the electrodes. After the breakdown of the layer, the crater is formed in the layer, and it becomes a source of additional ionization and excitation processes, which have an effect on the entire discharge in the electrode system because these ionization processes provide new ions into the interelectrode space. Although the ionization mechanism within the crater is not fully understood, it is expected that the electrons crossing the porous layer (fly ash deposit) ionize gaseous molecules within the pores or excite the atoms and compounds forming the layer and, for larger current densities, can cause thermal ionization. Besides many laboratory and industrial-scale studies, the discharge to fly ash layer remains still one of the most important and unsolved problems in electrostatic precipitators because it decreases the collection efficiency.

For particles larger then 1 μm, the dominating charging mechanism is the field charging. A particle of diameter $2R_p$ crossing ionic space charge of density $en_i$ in which the electric field magnitude is $E$, is charged with the rate [45]:

$$\frac{dq_p}{dt} = 3\pi e n_i \mu_i E R_p^2 \frac{\varepsilon_r}{\varepsilon_r+2}\left[1-\frac{q_p(\varepsilon_r+2)}{12\pi\varepsilon_0\varepsilon_r E R_p^2}\right]^2 \quad (1)$$

where $\varepsilon_r$ is the relative permittivity of the particle, $\mu_i$ is the gaseous ion mobility. After the infinite time of charging, the charge on the particle is saturated to the magnitude given by the Pauthenier equation [34]:

$$q_s = 12\pi\varepsilon_0 R_p^2 E \frac{\varepsilon_r}{\varepsilon_r+2} \quad (2)$$

The saturation charge is independent on ion concentration, provided $n > 0$.

The accumulation of charge on fly ash layer decreases the collection efficiency of electrostatic precipitator by three ways: First, the electric field generated by this charge is superimposed with the electrode's field that decreases the effective field $E$ in the precipitation space, and near the discharge electrode that reduces the discharge current and space charge density $n_i$ and consequently the charging rate (cf. Eq. (1)). Secondly, lower electric field $E$ between the electrodes results in decreased level of charge $q_p$ on

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the particles, which are charged due to the field mechanism. Because both $q$ and $E$ are decreased, the force driving the particle to the collection electrode, determined from the product

$$F = q_p E \quad (3)$$

also decreases. Finally, after breakdown the fly ash layer, the ions of polarity opposite to those emitted by the discharge electrode neutralize those emitted by the discharge electrode further decreasing the space charge, or collide with oppositely charged particles decreasing their charge $q_p$. Lower particles' charge results in further decrease in the collection efficiency of electrostatic precipitator. This effect is more pronounced for thicker fly ash layers, which sustains higher electric charge on the layer, and decreases the potential difference between the discharge electrode and the layer.

The most comprehensive studies of back discharge have been carried out by Masuda and Mizuno [29–31] and Cross [4,5] but the authors did not use spectroscopic methods in their investigations. The physical phenomena occurring in fly ash layer after breakdown and in the interelectrode space are still difficult to explain and their understanding requires further investigations. The research presented in this paper, employing optical emission spectroscopy, is aimed at better understanding the phenomenon of this type of discharge specific to electrostatic precipitators.

In the literature, optical spectroscopy has been used to study various electrical discharges in gases (cf., for example, Refs. [2,9,14,43]). The theory of quantitative analysis of plasma by using spectroscopy methods was considered by Griem [13]. Recently, laser spectroscopic techniques have been employed in order to determine the spatial distribution of the species such as OH [10,11,19,20,26], NO [38,40]; or $N_2$ [28,41] within and outside the plasma column. The results of back discharge analysis from the emission spectra in air were presented in our former papers [6,7,15,36].

In the present studies, we have used the method of emission spectroscopy in optical and infrared spectral range in order to learn about the processes taking place in discharges in gas mixture simulating flue gas leaving the coal fired boilers. This technique is an accurate and non-disturbing method of plasma diagnostics, which is capable of detecting gaseous elements at ppm level, via analysis of light emitted by excited or ionized atoms and molecules in the gaseous phase. The spectroscopic data can provide information on vibrational and rotational states of molecules, and excitation or ionization states of atoms. From these data, a type of discharge and relative concentration (abundance) of exited species present in the discharge space can be inferred. In the case of discharge in electrostatic precipitator, we can also learn about the elements volatilized from fly ash layer. The current–voltage characteristics of discharge, visual forms of the discharge, and spectroscopic analysis of ionization and excitation states of gaseous molecules in the discharge for the collection electrode covered with fly ash layer were compared with those for clean collection electrode. The emission spectroscopy helps to understand physical processes occurring in the discharge plasma. For the purpose of this paper all the data on spectral lines wavelengths were taken from the books of Pearse and Gaydon [35] and Striganov and Svetnickij [42].

We have also shown that discharge characteristics in flue gas are different from those occurring in ambient air [7], and the measurements carried out for simplicity in air, as frequently reported in many papers, cannot be representative to the discharges taking place in electrostatic precipitators.

## 2. Experimental

A schematic of experimental set-up used in these investigations is shown in Fig. 1. The discharge was generated between stainless steel needle with a tip radius of about 15 μm and cone half-angle about 15° and a nickel steel plate of diameter of 100 mm. The distance between the tip of the needle and the metal plate was 20 mm. The electrodes were placed near the centre of a cube chamber of the edge length of 160 mm, made of PMMA. For investigating back discharges, the grounded plate was covered with fly ash layer of thickness of 5 mm. The discharges were generated in gas mixture composed of 15 vol.% of $CO_2$, 4.1% $O_2$, 0.9% Ar and the rest of $N_2$, simulating flue gas leaving coal-fired boilers, at

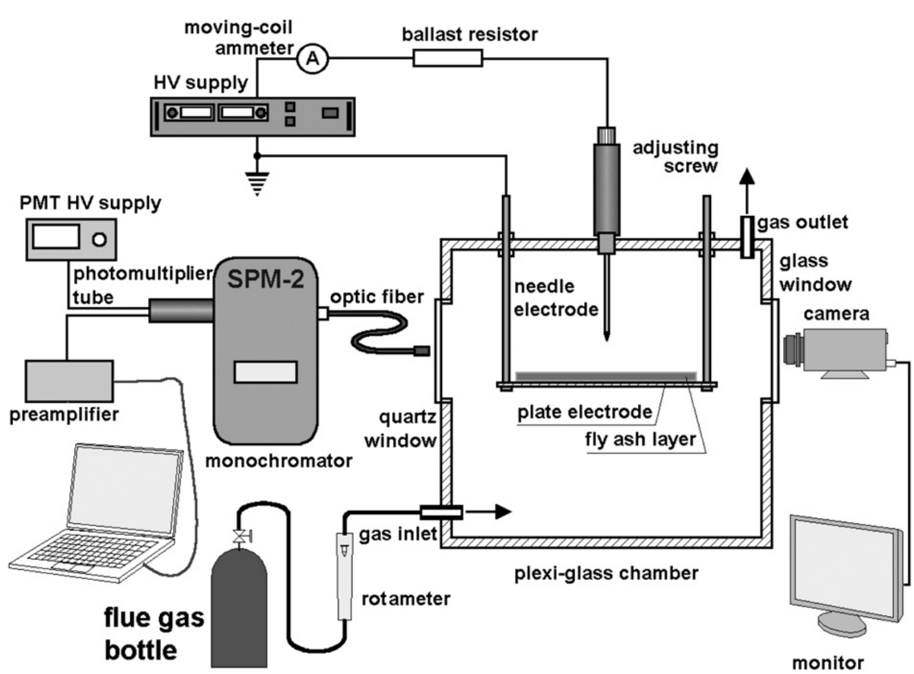


**Fig. 1.** Schematic of experimental set-up.