Electric field and charge distribution in back discharge in point-plane geometry

A. Krupa

Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszeria 14, 80-952 Gdansk, Poland
E-mail: krupa@imp.gda.pl

Abstract. The paper presents experimental and theoretical investigations of electric field and charge distribution on the fly-ash layer covering the plate electrode in the back discharge in point-plane geometry. Two kinds of dielectric layer were used in the experiments: highly resistive fly-ash from an electrostatic precipitator and a dielectric plate (PET) with a small pinhole.

1. Introduction
Back discharge is a type of electric discharge that occurs in electrostatic precipitators, used for removal of particulate matter from coal-fired power plants, when low sulphur coal is burned. Ions generated in the vicinity of the discharge electrode accumulates on the surface of the dielectric layer (fly-ash deposit) and causes an increase in the magnitude of electric field within this layer. This charge causes also a decrease in the magnitude of electric field in the interelectrode space. An increase of electric field within the layer, leads to the breakdown of this layer. Initially the charge accumulated on the layer surface flows through small channels to the plate electrode, and faint, glowing spots can be visible on the layer surface. An increase of the voltage and discharge current leads to an increase in the current density in these channels that causes heating of the material of the layer. When sufficiently high current flows through one such channel, it becomes conducting due to thermal ionisation of the layer material. These ionization processes on the layer surface lead to gaseous discharges such as glow or breakdown streamers to occur and finally the arc discharge can be incepted at lower voltages than without the dielectric layer. Effects of gas composition on characteristics of the back discharge were investigated by Masuda et al. [1, 2]. The current-voltage characteristics of back-discharge were presented in [3] and spectroscopic studies of the discharge in [4]. A back-corona discharge was also tested as a plasma source for decomposition of hydrocarbons [5]. The investigations of the motion of dust particle emitted from the collection electrode were studied in the paper [6]. The paper [7] presents investigations of back discharge occurring in air and flue gases produced by the process of burning of LPG or charcoal. The aim of that work was to determine an effect of back discharge on morphology of fly ash layer and exhaust gas composition. In the present paper, back discharge generated in needle-to-plate electrode configuration, with the plate electrode covered with a dielectric layer, is investigated. The aim of this work was to determine the surface charge density before back corona occurred, and the rate of charge decay on the layer. The distribution of surface charge density deposited on the fly-ash...
layer was also measured in the vicinity of the crater after a breakdown streamer occurred, and after switching off the high voltage.

2. Experimental set-up
Schematic of the experimental setup is shown in Figure 1. The back discharge is generated in a needle-to-plate electrode configuration with the plate electrode covered with a dielectric layer. The distance between needle tip and plate was fixed at 35 mm. Fly-ash of high resistivity taken from power plant Tarong Energy Australia was used in the experiments. Additionally, a dielectric plate (PET) with a small pinhole in the middle was used in the experiments for reference. The dielectric plate allowed the generation of highly localized and repeatable back discharges. The discharge was generated in air at a fixed temperature in the range of 20 to 120°C. The structure of the fly-ash layer deposited on the collection electrode depends on the discharge current density and the radial position from the needle electrode axis. The surface charge density and the rate of charge decay on the fly ash layer was measured before back corona occurred. The distribution of surface charge density deposited on the fly-ash layer was also measured in the vicinity of the crater after a breakdown streamer, just after the high voltage was switched off. In the experiments a precision electrostatic voltmeter, Trek Model 341B, employing the field-nulling technique for noncontact measurement of voltage was used. The electrostatic voltmeter was equipped with high Temperature Probe (up to 100 °C) Model 3453ST (side-viewing). This permits stationary measurements of charge decay at a fixed point, and measurement of surface charge distribution along the radial coordinate of the dielectric sample via moving the side-viewing probe above the surface of the dielectric layer.

3. Results
The surface charge density distributions on the PET plate are presented in Figures 3 and 4. The effect of the diameter of the circular opening in the plate is shown on Figure 3. The magnitude of surface charge density on the PET layer outside the opening is nearly the same, but in the vicinity of the opening the surface charge density decreases. The distribution of charge accumulated on the PET plate without opening and with an opening of diameter 1 mm for the charging voltages 17 kV and 19 kV is presented in Figure 4. Figure 5 shows the radial distribution of surface charge density after the corona discharge. In a zone of about 10 mm from axis of the needle, the surface charge density is nearly constant. Out of this zone, the level of charge density decreases with the distance. This phenomenon is probably caused by the combined effect of charge distribution on the layer following the Warburg law, and differences in density of the fly ash layer. Just below the needle, the layer is highly packed due to ion bombardment. The average dielectric constant is larger and resistivity of the packed layer is lower (because of smaller air voids). As an effect, the deposited charge is higher due to Warburg law in spite of higher conductance in this zone. In the less-densely packed layer the surface charge density is lower.
due to lower ion current density flowing to the layer. In Figure 5b, the distribution of surface charge density on the fly-ash layer with a crater remaining after the discharge is presented.

**Figure 3** Surface charge density distribution on the PET plate for various opening diameters.

**Figure 4**. Surface charge density distribution on the PET plate with opening of diameter 1mm for various charging voltages.

a) continuous layer

**Figure 5**. Surface charge density distribution on the highly resistive fly-ash layer. The discharge needle axis in the position 50 mm

b) back discharge crater in the position 45 mm

**Figure 6** Maximum surface charge density (near the needle axis) on the highly resistive fly-ash layer vs. discharge voltage

**Figure 7** Electric field distribution in the needle to plate geometry with back discharge crater in dielectric layer. Discharge voltage 25 kV.
The maximum surface charge density on the fly ash layer (near the axis) vs. charging voltage is shown in Figure 6. The charge density increases with the voltage up to a certain maximum, and with higher charging voltage, it starts to decrease. This effect can be explained by the results of measurements presented in Figure 8, which show the time resolved decay of charge on the layer. For lower voltages (Figure 8a), the charge decreases slowly and smoothly due to conduction current through the layer and/or the surface current. Only at the beginning of the charge decay, a small jump of charge can be noticed. In the case of higher voltages (Figure 8b), the charge decay is stepwise. The few jumps in charge density are the result of electric breakdown through the layer leading to local charge neutralization in the breakdown points. This stepwise decay disappears when the surface charge density decreases below 0.05 mC/m². From the value of charge density the electric field through the layer can be determined. The estimated electric field magnitude is of the order of 2 MV/m and is close to the breakdown field of air (3 MV/m). The breakdown results in a shorter average time constant for charge decay at higher charging voltages. Numerically obtained electric field distribution in the needle to plate geometry with a back discharge crater in the dielectric layer in the axis is presented in Figure 7. It can be seen from this simulation that the magnitude of the electric field within the crater increases similarly to the needle tip and can lead to ionization processes.

![Image](image_url)

**Figure 8** Surface charge decay on the highly resistive fly-ash layer in the position 5 mm off the axis.

4. Summary
The paper presents experimental and theoretical investigations of electric field and charge distributions on the fly-ash layer covering the plate electrode in a back discharge in point-plane geometry. The experiments were carried out for highly resistive fly-ash from Australia and dielectric plate (PET) with a small pinhole, in the middle. The presented results of charge distribution measurement provide information on the mechanisms of back discharge onset and the effect of current density, resistivity of fly-ash on the discharge onset and charge decay from the dielectric layer surface. The research is aimed at better understanding of the back-discharge processes which cause harmful effects in electrostatic precipitators.

Acknowledgement
This research work was supported by the Polish Ministry of Science and Higher Education within the Project No.3520/B/T02/2000/37.

References
[1] Masuda S, Mizuno A, 1977/1978 J. Electrostatics 4 35
[2] Masuda S, Mizuno A, 1978 J. Electrostat. 5 215
[3] Rajch E, Jaworek A, Sobczyk A, Krupa A, 2006 Czech. J. Phys. 56 B803
[4] Czech T, Lackowski M, Krupa A, Sobczyk A, Jaworek A, Rajch E, 2009 European Phys. J. D 54 265
[5] Jaworek A, Krupa A, Czech T, 1996 J. Phys. D Appl. Phys. 29 2439
[6] Krupa A, Lackowski M, Czech T, 2006 Environment Protection Engineering 32 53
[7] Krupa A. 2009 J. Electrostatics 67 291