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Experimental Study of Corona Discharge Generated in a Modified Wire–Plate Electrode Configuration for Electrostatic Process Applications
Abdelber Bendaoud, Senior Member, IEEE, Amar Tilmatine, Senior Member, IEEE, Karim Medles, Mohamed Younes, Octavian Blejan, and Lucian Dascalescu, Fellow, IEEE

Abstract—Parallel wire–plate electrode arrangements are widely used to generate corona discharges in various electrostatic processes. This paper analyzes the characteristic features of a slight modification of such an electrode configuration. In all the experiments, a stainless steel wire of diameter 0.18 or 0.57 mm was used as the corona electrode, energized from a reversible dc high-voltage supply. The modified two-level grounded electrode consisted of three metallic plate segments, which are parallel to the wire and located at 20, 15 (or 10), and 20 mm from it, respectively. In a first set of experiments, the current–voltage characteristics of this electrode arrangement were obtained for both polarities of the high-voltage supply and compared to those of a standard wire–plate electrode system. In a second set of experiments, two of the plate segments were made of several aluminum strips insulated from each other and successively connected to a microammeter, in order to characterize the distribution of the corona current at the surface of the modified grounded electrode. The third set of experiments described in this paper was performed with the corona electrode energized from a rotary spark gap connected at the output of the dc high-voltage supply. Finally, the possibility of applying this modified electrode configuration for the precipitation of dust contained in flue gases is briefly discussed.

Index Terms—Corona discharge, electrostatic precipitator, rotary spark gap.

I. INTRODUCTION

RECIPITATION of dusts, spraying of powders, separation of granular mixtures, and flue gas treatment are only a few of the industrial applications of corona discharges [1]–[8]. The particles of dust, the powders, or the granular materials processed in electrostatic precipitators, sprayers, or separators, respectively, are charged by the ions generated in such discharges. The electric forces that act on the corona-charged particulate matter achieve the dust collection, the powder deposition, or the granule separations [9]–[11]. In plasma chemical reactors, the corona discharge transfers to the treated gas the energy that is necessary to decompose the pollutants [12].

Much work has already been done to characterize the various types of corona electrodes and to calculate the electric field strength, as well as the ionic charge density that they generate [13]–[19]. Indeed, the efficiency of any such electrostatic process depends not only on the maximum magnitude but also on the spatial distribution of the electric field strength and of the ionic charge density in the corona discharge. Various constructions have been described in technical literature [15], [16], accompanied by current–voltage curves that enabled their comparison under certain well-defined conditions (distance to a grounded electrode and polarity of the high-voltage electrode).

Corona discharge in wire–plate electrode arrangements has been thoroughly investigated, mostly in relation with the design of high-voltage dc and ac power transmission lines [20]–[22]. Experimental studies have clarified important practical issues, such as the onset voltage level of the corona discharge, power losses, and the influence of ambient conditions (humidity, wind, ...). Researchers elaborated sophisticated numerical models for calculating the electric field and the space charge generated by an ionizing wire facing a plate electrode [23], [24].

Accurate numerical models have also been validated for the study of two other electrode configurations, which are typical for electrostatic precipitators: wires between parallel plates connected to the ground and coaxial wire–cylinder electrodes [25]–[27]. These studies aimed at improving the efficiency of the electrostatic precipitation process, which is known to depend on the migration velocity of the charged particles toward the collector electrode. There are two ways of improving the collection efficiency of a precipitator:

1) increase the migration velocity, by maximizing the charge carried by the particles and the strength of the electric field in which they evolve;

2) decrease the velocity of the gas.

In the wire–plate electrode arrangement, the simplest way to increase the electric field strength and also the space charge density would be to reduce the interelectrode spacing, but this would modify the gas velocity: The particles would spend less time in the corona discharge, and for a given length of the collector electrode, the probability for them to precipitate decreases. The effect of the gas flow field is particularly strong.
for smaller particles (less than 1 μm in diameter). Solutions should be found to better charge these particles and intensify the electric field that acts on them without increasing the average velocity of the gas in the precipitator.

In a recent paper, two of the authors pointed out the spectacular modification of the corona current density distribution generated by a local reduction in the cross-sectional area of a standard coaxial wire–cylinder precipitator [13]. They report a significant improvement of the collection efficiency of the modified precipitator, as compared to the standard installations of similar dimensions. Would it be beneficial to modify in a similar way the standard wire–plate electrode configuration of the electrostatic precipitators?

The aim of this work is to give an answer to this question, by characterizing the corona discharge generated between an electrode wire, connected to a dc high-voltage supply, and several plate segments that are parallel to that wire and located at different distances from it. It is expected that the density of the corona current and the intensity of the electric field will increase in certain sections of the device, improving the corona charging of the particles, while the average velocity of the gas will remain practically the same.

II. EXPERIMENTAL SETUP

The corona discharge was generated using the so-called “dual-type electrode,” which is composed of a thin tungsten wire of length 198 mm and diameter 0.18 or 0.57 mm, attached to a copper cylinder of diameter 20 mm, which serves as the mechanical support to the ionizing element, as shown in Fig. 1. The ionizing wire and the supporting cylinder were energized from the same reversible dc high-voltage supply (model SL300, Spellman, Hauppauge, NY). The two elements were parallel, and the plane defined by their axis was perpendicular to the grounded electrode.

The experiments were performed with several models of grounded electrodes. The “standard” one-level grounded electrode, designated as model #1, consisted of a metallic (aluminum) plate, spaced at 20 mm from the ionizing wire, as shown in Fig. 1(a). The “modified” two-level grounded electrodes, designated as model #2.1 and #2.2, were confectioned of 12 aluminum strips glued at the surface of a two-level insulating support, as shown in Fig. 1(b). The distance between two strips was 2.2 mm on the lower level and 1 mm on the upper level of the grounded electrode (Fig. 2). The spacing between the ionizing wire and the lower level of the grounded electrode was \( d_2 = 20 \text{ mm} \). The upper level of the grounded electrode was located at \( d_2 = 15 \text{ mm} \) and \( d_2 = 10 \text{ mm} \) from the ionizing wire, for model #2.1 and #2.2, respectively.

In some experiments, the various electrode arrangements were energized from a rotary spark gap connected at the output of the reversible dc high-voltage supply (Fig. 3).

III. EXPERIMENTAL PROCEDURE

In a first set of experiments, the current–voltage characteristics of model #2.1 and #2.2 were compared to those obtained
for the standard wire–plate electrode arrangement (model #1), at both polarities of the high-voltage supply. The current was measured with an analog microammeter. The high voltage was indicated on the front panel of the power supply. An experiment was carried out using also a separate high-voltage probe, to confirm the accuracy of the readings. Represented on the $I-V$ characteristics are the current values recorded right after corona onset or before sparkover.

For the second set of experiments, a microammeter was connected successively between the ground and each of the 12 aluminum tapes of the collector electrode. It was thus possible to determine the distribution of the current density along the two surfaces (lower level and upper level) and along the lateral surface of the grounded electrode arrangement. Each experiment was replicated three times.

In a third set of experiments, the current–voltage characteristics and the distribution of the corona current at the surface of the grounded electrode were obtained for the wire electrode energized from the rotary spark gap connected at the output of the reversible high-voltage supply.

All the experiments were performed in the absence of dust or gas flow, in ambient air (temperature: $22 \pm 1 \, ^\circ\text{C}$; relative humidity: $43 \pm 2\%$).

IV. RESULTS AND DISCUSSION

A. Current–Voltage Characteristics

The current–voltage characteristics obtained for model #1, #2.1, and #2.2 at negative polarity can be examined in Figs. 4 and 5. At a given voltage, the corona current generated by the modified electrode arrangements is higher than that obtained with the standard wire–plate system. The explanation is that the electric field is more intense, and hence, the corona current density is higher at the upper level of model #2.1 and #2.2.

TABLE I

<table>
<thead>
<tr>
<th>Wire diameter [mm]</th>
<th>$\phi_w = 0.18 , \text{mm}$</th>
<th>$\phi_w = 0.57 , \text{mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage [kV]</td>
<td>$U_c = 7.5; U_s = 17$</td>
<td>$U_c = 10; U_s = 18.5$</td>
</tr>
<tr>
<td>Current [\mu A]</td>
<td>$I_c = 0.15; I_s = 100$</td>
<td>$I_c = 0.3; I_s = 72$</td>
</tr>
</tbody>
</table>

TABLE II

<table>
<thead>
<tr>
<th>Wire diameter [mm]</th>
<th>$\phi_w = 0.18 , \text{mm}$</th>
<th>$\phi_w = 0.57 , \text{mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage [kV]</td>
<td>$U_c = 6.6; U_s = 13.5$</td>
<td>$U_c = 9.5; U_s = 16$</td>
</tr>
<tr>
<td>Current [\mu A]</td>
<td>$I_c = 0.9; I_s = 95$</td>
<td>$I_c = 0.35; I_s = 70$</td>
</tr>
</tbody>
</table>

Fig. 7. Corona current densities obtained at a high voltage $U = \pm 17 \, \text{kV}$ for model #2.1 ($d_2 = 15 \, \text{mm}$; wire diameter: 0.18 mm).

At negative polarity, the corona current is higher, in absolute value, than that at a similar high voltage of positive polarity, as can be seen by examining the current–voltage characteristics in Fig. 6. The corona onset voltage $U_c$ and the sparkover voltage $U_s$ for $d_2 = 15 \, \text{mm}$ (model #2.1) and $d_2 = 10 \, \text{mm}$ (model #2.2), as well as the respective currents $I_c$ and $I_s$, can be read in Tables I and II.

This is why the negative polarity is preferred in most electrostatic precipitation applications. However, most of the experiments that will be presented in the following sections of this paper were done at positive polarity, for which the corona discharge was more stable.

B. Corona Current Density Distribution

The distribution of the current density for model #2.1 ($d_2 = 15 \, \text{mm}$), with a wire diameter of 0.18 mm, is shown in Fig. 7, for $U = 17$ and $-17 \, \text{kV}$. The density is higher for the negative polarity, in each point at the surface of the collector electrode. Similar results were obtained for model #2.2.

The aspect of the current density distribution curves is similar to that for the 0.57-mm-diameter wire. As expected, smaller current density values were obtained at a given voltage level.
ergization should be examined as a solution for electrostatic spark gap (Fig. 10). The superposition of pulsed and dc energization obtained for various pulse frequencies generated by the rotary spark gap.

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The aspect of the pulse generated by the rotary spark gap device can be examined in Fig. 8. At the frequency \( f = 125 \text{ Hz} \), the corona current is higher, in absolute value, than that obtained at \( f = 62.5 \text{ Hz} \). The overall current is smaller than that in the case of dc energization.

This observation is confirmed by the current density curves of pollutants.

C. Pulsed Energization

The modified electrode arrangement has current–voltage characteristics and current density distributions that are more advantageous for electrostatic precipitation than those of standard devices. They are expected to provide the following:

1) better particle charging, by intensifying the electric field strength in the sections of the precipitator with smaller interelectrode spacing;

2) higher collection efficiency for particles of all sizes, by reducing the gas velocities through the sections characterized by a larger inter-electrode spacing.

Further work is needed to validate these predictions by carrying out collection efficiency experiments with various types of pollutants.

V. Conclusion

REFERENCES


Karim Medles was born in Tipaza, Algeria, in 1972. He received the M.S. and Dr.Eng. degrees in electrical engineering and the Ph.D. degree, with a thesis that he partly prepared at the University Institute of Technology, Angouleur, France, with an 18-month research scholarship awarded by the French Government, from the University Djillali Liabès, Sidi Bel Abbès, Algeria, in 1994, 1995, and 2006, respectively.

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Lucian Dascalescu (M’93–SM’95–F’09) received the Dipl. Eng. degree (with first-class honors) from the Faculty of Electrical Engineering, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, in 1978, the Dr. Eng. degree in electrotechnical materials from the “Politehника” University of Bucharest, Bucharest, Romania, and the Dr. Sci. degree and the “Habilitation à Diriger de Recherches” diploma in physics from the University “Joseph Fourier,” Grenoble, France.

His professional carrier began at CUG (Heavy Equipment Works), Cluj-Napoca. In 1983, he moved to the Technical University of Cluj-Napoca as an Assistant Professor, later becoming an Associate Professor of electrical engineering. From October 1991 to June 1992, he received a research fellowship at the Laboratory of Electrostatics and Dielectric Materials, Grenoble, where he returned in January 1994, after one year as an Invited Research Associate and Lecturer at Toyohashi University of Technology, Toyohashi, Japan, and three months as a Visiting Scientist at the University of Poitiers, Poitiers, France. For four years, he taught a course on electromechanical conversion of energy at the University Institute of Technology, Grenoble. In September 1997, he was appointed Professor of electrical engineering and automated systems and Head of the Electronics and Electrostatics Research Unit, University Institute of Technology, Angoulême. Since 1999, he has been the Head of the Department of Management and Engineering of Manufacturing Systems. He is currently the Head of the Electrostatics of Dispersed Media Research Unit, which is part of the EHD Group, P’ Institute, CNRS-University of Poitiers-ENSMA, IUT, Angoulême, France. He has been invited to lecture on the electrostatics of granular materials at various universities and international conferences in China (1988), Poland (1990), USA (1990, 1997, 1999, and 2008), Japan (1993 and 2009), France (1993 and 2008), Great Britain (1998), Romania (1999, 2004, and 2006), Canada (2001), Belgium (2002), and Algeria (2005, 2006, and 2009). He is the author or coauthor of more than 110 papers and is the author of several textbooks in the field of electrical engineering and ionized gases. He is the holder of 15 patents.

Prof. Dascalescu is a Fellow of IEEE Industry Applications Society (IAS) and a member of the Electrostatics Society of America, the Electrostatics Society of Romania, Société des Electriciens et Electroniciens (SEE), and Club Electrotechnique. Electronique, Automatique (EEA) France. He is also the Vice Chair of the IEEE France Section, and the Past Chair and Technical Program Chair of the Electrostatic Processes Committee of the IAS.