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Review

Computation and measurement of corona current density and V–I characteristics in wires-to-plates electrostatic precipitator

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A R T I C L E I N F O

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A B S T R A C T

This paper deals with experimental and numerical investigation of wire-duct type electrostatic precipitator under clean air conditions. A laboratory-scale model is used to provide measurements of corona current–voltage characteristics and current density. Different configurations of electrodes are tested in order to improve the performance of the electrostatic precipitator. Moreover, the corona governing equations are successfully solved using Comsol Multiphysics. The present work simulates the whole geometry including all discharge wires in order to take into account their mutual effect. The results of the numerical model are compared with the experimental measurements of current density and current–voltage characteristics and the general agreement is quite good.

Contents

1. Introduction

Corona discharge is currently found at the basis of an increasing number of industrial and technological applications such as electrostatic precipitator (ESP) and separators, surface treatment, ozone generator, electrophotography, painting and spraying powders, etc. Moreover, it has been the subject of many theoretical, experimental and numerical studies in diverse gaps configurations [1–19]. In this paper, we are interested about the experimental investigation and numerical modeling of a wires-to-plates electrostatic precipitator (WP-ESP) under normal atmospheric air

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conditions.

Because of the distortion of the electric field due to the presence of the space charge, the equations governing the corona ionized fields are difficult to solve analytically. Various numerical techniques and approaches were then developed to arrive at numerical solution using the charge simulation method [2,3], the finite difference method [4–7] and the finite element method [8–15], often combined with the method of characteristics [13–15] or the donor-cell method [9,16] to evaluate the space charge density. Hence, many studies have attempted to find a numerical solution of the corona problem of different ESP configurations, such as the wires-to-plates geometry. However, most of these studies have limited the calculation domain around single wire [3,5–9,14,17] due to some computational difficulties [18], and the results often extrapolated to predict the effect of the other wires. Instead, the present study simulates the entire domain of study in order to take into account the influence of all ionizing wires and their shielding effect. This is achieved by using Comsol Multiphysics, which is a powerful software tool for numerical calculation of partial differential equations. The corona coupled equations are solved using two application modes; PDE (*General Form*) mode for electric potential distribution and *Convection and Diffusion mode* for charge transport equation. The developed program allows the simulation of the Multi-wires-to-plates type electrostatic precipitator, of which a laboratory scale prototype has been realized to validate the numerical model.

2. Experimental set-up and procedure

Conventional wires-to-plates type precipitator (WP-ESP) consists of two parallel plates (1) and a set of corona wires (2) of radius R_w that hang horizontally midway between the grounded plates (cf. Fig. 1). The wires, at a regular spacing '*a*', are set with two insulating props (3) at height *h* from the passive electrodes. Direct voltage V_a, supplied by a 0 to ±140 kV source (HVS), is applied to the wires. The current collector A (4) with a diameter of 4.5 mm is incorporated on the bottom plate and connected to a current measuring device (pA). The upper plate and the bottom one, used as a measuring plane, are of dimensions 500 × 770 mm^2, 1 mm thickness, and are made of stainless steel. The bottom plate is set with insulating props (5), which are placed on a grounded copper plates (6) and the whole is supported on wood props (7), while the upper plate rests on the two insulating props (3) which set the wires. To obtain spatial distributions of the current density, the insulating props (3) are free to move in x-direction, so that the current collector 'A′ moves relative to the wires along the measuring plane, enabling thus the measurement of several values of the current density over the plate. To measure the applied voltage V_a, we have used a resistive voltage divider comprising a high voltage resistor R_a (248.5 MΩ) and a low voltage resistance R_u (501 kΩ) incorporated into a digital voltmeter (V). These two resistors are connected by coaxial cables [19].

We have experimented with various configurations of the WP-ESP such as; the variation of the number of wires (from 1 to 5 wires); the variation of the wires spacing *a* (40, 60 and 80 mm) and the variation of the wires radius R_w (0.2 and 0.4 mm), and in each case, the applied voltage was varied. During experiment, the pressure, temperature and relative humidity are systematically recorded to be inserted into the numerical program (to calculate the normalized threshold field), since corona largely depends on atmospheric conditions [1].

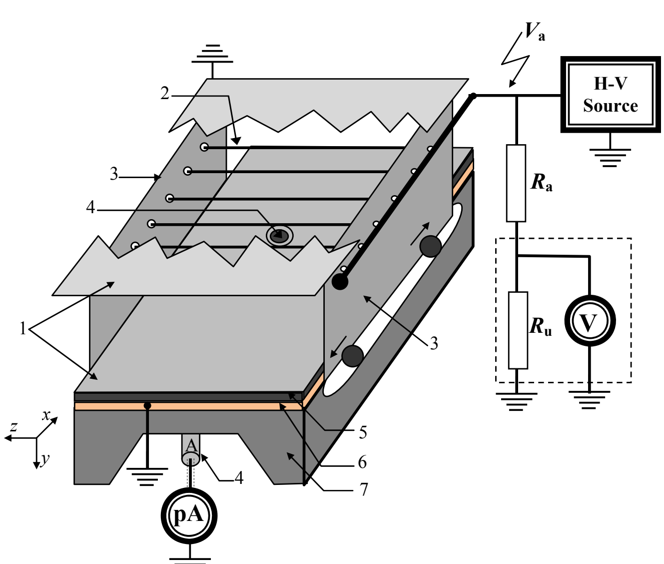

Fig. 1. General view of the experimental setup.

3. Modeling and numerical simulation

Fig. 2 shows a schematic view of the wires-to-plates type precipitator. It consists of several parallel wires of radius R_w, equidistantly spaced, and stretched horizontally at a height *h* in the middle of two grounded plates. Assuming the precipitator to be infinitely long (in z -direction), a 2-D computation model can be considered.

3.1. Corona governing equations

When sufficient high voltage is applied to the WP-ESP, corona discharge occurs around the wires. The space-charge environment may be divided into two different regions (cf. Fig. 2); ionization regions surrounded the active wires where free charges are produced, and a drift region occupying the remainder of the interval (between wires and the ground plates) where positive or negative ions (according to the applied voltage polarity) migrate to the grounded plates due to the coulomb forces. Also, the local value of the electric field strength $\boldsymbol{E}$ depends not only on applied voltages and conductor geometry, but also on the generated space-charge.

In the air, the mathematical description of the monopolar ionized fields is giving by this set of equations:

Poisson's equation:

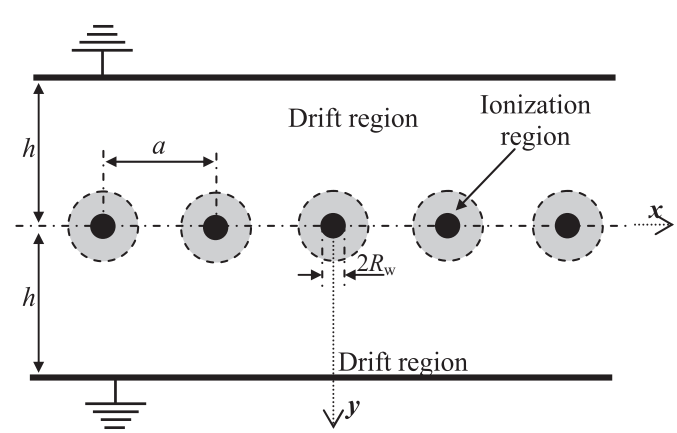

Fig. 2. 2D cross-sectional view of WP-ESP.