Two-Dimensional Simulation Images of Pulsed Corona Discharges in a Wire–Plate Reactor

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***Abstract*—Two-dimensional time-dependent numerical simulations on a pulsed corona discharge are presented in a wire–plate reactor. The discharge modeling includes the three modules for the corona discharge, reactive species generation, and plasma properties. Two-dimensional images of the electron density and electric field intensity illustrate that streamer propagation is strongly influenced by the reactor geometry, particularly, the neighboring wire distance.**

***Index Terms*—Neighboring wire electrodes effect, numerical modeling, pulsed corona discharge, streamer propagation, wire–plate reactor.**

IN RECENT years, a pulsed corona discharge has been suggested as a new plasma source for decomposing air pollutants, such as NO_x and SO_x. Since wire–plate reactors have been most extensively investigated for flue gas cleaning, understanding pulsed corona discharge physics in these devices is important to determine the optimal design parameters, such as wire radius, wire-to-plate distance, and even neighboring wire distance. In previous work, numerical simulations of streamer corona discharges were focused mainly on plate–plate [1] or single pin–plate [2], [3] geometries. In this study, two-dimensional (2-D) time-dependent simulations are carried out in more realistic wire–plate geometries. In particular, the influence of neighboring wire distances on the streamer propagation is presented.

The pulsed corona discharge modeling employed in this work includes three modules for the corona discharge, reactive species generation, and plasma properties. A 2-D time-dependent model for the corona discharge consists of Poisson's equation for the electric potential and continuity equations for density of charged particles. Reactive species, such as N, O, and OH radicals, generated by energetic electron collisions with air molecules are taken into account by a set of rate equations. Plasma properties and reaction rate coefficients of electron–air interactions, such as ionization, attachment, dissociation, and excitation, are calculated by using the Boltzmann equation solver, ELENDIF, and the JILA cross-section data [4].

The rectangular coordinate system (x, y) is transformed into curvilinear coordinates (ξ, η) to handle the surface of wire electrode effectively. A curvilinear numerical grid system is generated by means of the 2-D elliptic partial-differential-equation method. The governing equations transformed into the (ξ, η) coordinates are solved by finite difference methods, which use a conjugate gradient scheme for Poisson's equation and an upwind scheme for the electron continuity equation. Although the upwind scheme is known to lead to a numerical diffusion when it simulates the electron convection at a high electric field, this scheme is still effective in the relatively low field discharge and its simulation images remain valid at least from the qualitative point of view.

For a numerical illustration of a wire–plate corona discharge, the radius of the anode wire is 0.2 cm and the distance between the center of wire and cathode plate is 2 cm. An external pulse voltage of 46 kV is applied to the anode wire and a spatially uniform electron distribution of 1 cm^{-3} is used as an initial condition. A numerical grid of 50×100 and time steps of 10^{-12} s are used for the calculations. Fig. 1(a) shows the calculated 2-D distributions of electron density and electric field intensity after 30 ns of the streamer corona propagation in the wire–plate reactor for a neighboring wire distance of 4 cm. A positive streamer corona initiated by air breakdown at the anode wire surface propagates toward the grounded cathode plate to form a discharge channel with an electron density of 10^{13} cm^{-3}. The initial nonuniform electric field, with maximum value of 78 kV/cm, gradually reduces to about 55 kV/cm as the polarization field is formed by net space charge produced by different drift speeds between electrons and ions.

In order to illustrate the influence of neighboring wire distance on the propagation characteristics of pulsed corona discharges, the simulation images produced by using a graphic software, Techplot 7, are compared in Fig. 1 for different wire-to-wire distances. Even though the same voltage is applied in the three cases, it appears that interactions between the electric fields near the neighboring wires occur with corresponding reductions in the electron density and electric field in the streamer head. As the adjacent wire electrodes are brought closer, their interference effects on electric field distributions become stronger and the streamers from adjacent wires consequently shrink up to considerably narrow ranges. It is, therefore, concluded that the wire-to-wire spacing should be at least twice the wire-to-plate distance to produce effective nonequilibrium plasma for enhancing the efficiency of the flue gas cleaning process.

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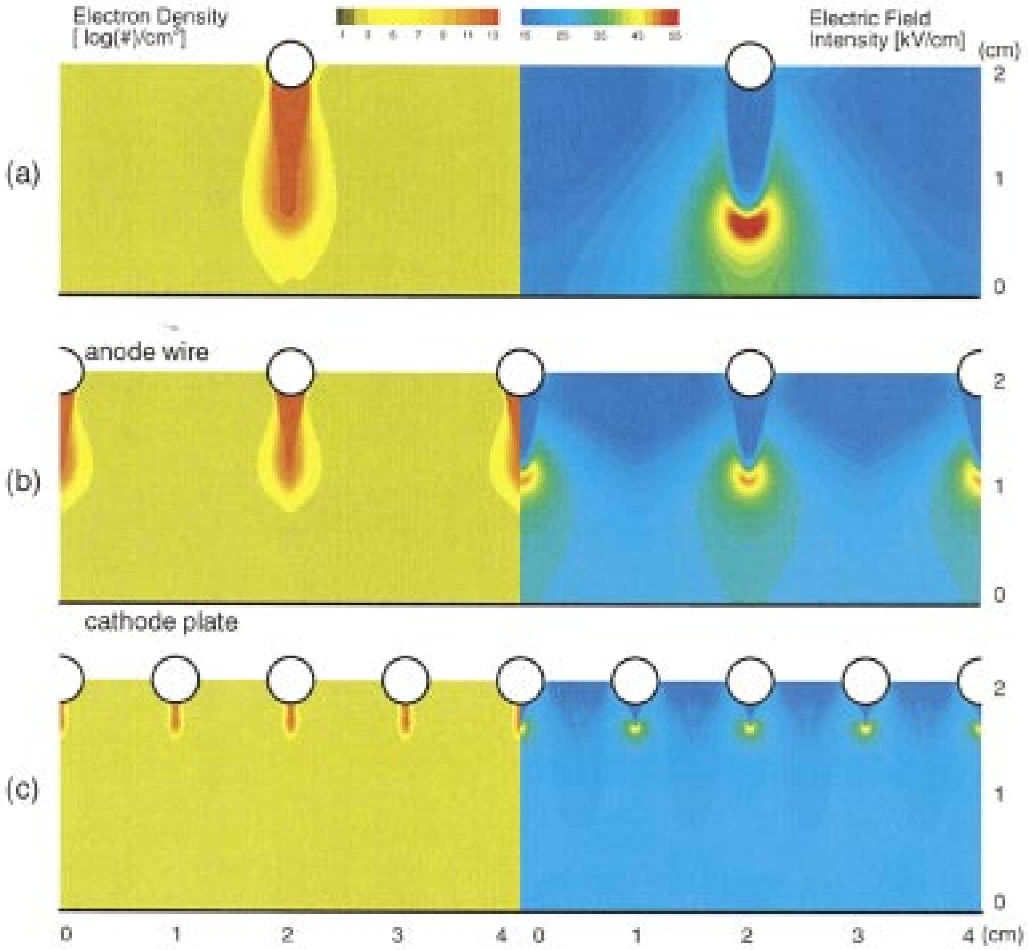

Fig. 1. Propagation images of electron density and electric field intensity after 30 ns of streamer generation in the wire–plate reactor (wire-to-plate distance = 2 cm, applied voltage = 46 kV) for different wire-to-wire distances of (a) 4 cm, (b) 2 cm, and (c) 1 cm.