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The role of negative corona in charged particle dynamics

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ABSTRACT

An improved hybrid numerical algorithm was utilized to simulate the charging properties and trajectory of the particles in an electrostatic precipitator. The corona discharge, migration and charging progress of particles were investigated in different conditions. The error of the traditional model can be reduced relatively and several conclusions can be given that the trajectory of the particles is different when considering corona or not. The electric field force, polarization force of the particles fluctuate with the movement of particles under the influence of the Trichel pulses in negative corona discharge, and the velocity and the charging characteristic of the particle are affected.

1. Introduction

The dust pollution caused by industrial production has become one of the most serious environmental problems with the development of modern industry and the consumption of fossil energy around the world. Therefore, further studies on the movement and charging mechanism of particles is needed to reduce the pollution produced by dust particles which will present significant risk to equipment operation, human security and atmospheric environment [1–4]. The charged particles are mainly produced by the corona of the high voltage conductor where negative voltage is applied. In order to improve the charging rate of particles and strengthen the corona effect, arista electrode was presented as a substitute for cylindrical electrode to enhance the inhomogeneity of electric field distribution in the electrostatic precipitation (ESP). Consequently, particles in corona discharge should be investigated with a close correlation between the movement of dust particles and electric field coupled with ion concentration for better accuracy.

Negative corona discharge can be maintained without the existence of the external ionization source when a negative voltage is applied to asymmetric electrodes such as a needle and a plate which is simplified by the model of arista electrode and a plate in ESP (Fig. 1) [5–8]. A portion of photons emitted by the collisions of electrons with molecules at the head of the electron avalanche in the corona discharge will be absorbed by molecules. Photoelectrons may be generated by these molecules. These photoelectrons can be used as seed electrons to produce new electron avalanche which called secondary electron emission avalanche (SEEA) [9–10]. Therefore, further studies on micro-physical processes of plasma have been developed in recent years [11]. In theory, a mathematical model by solving continuity equations coupled with Poisson's equation was developed by Morrow for the first time and the first Trichel pulse was obtained by numerical simulation [12]. Then Morrow's model was improved by Gupta who gained a more realistic conclusion that the current growth rate would be slowed down in the plasma formation process [13]. In order to obtain the following pulses, FEM-FCT method was utilized

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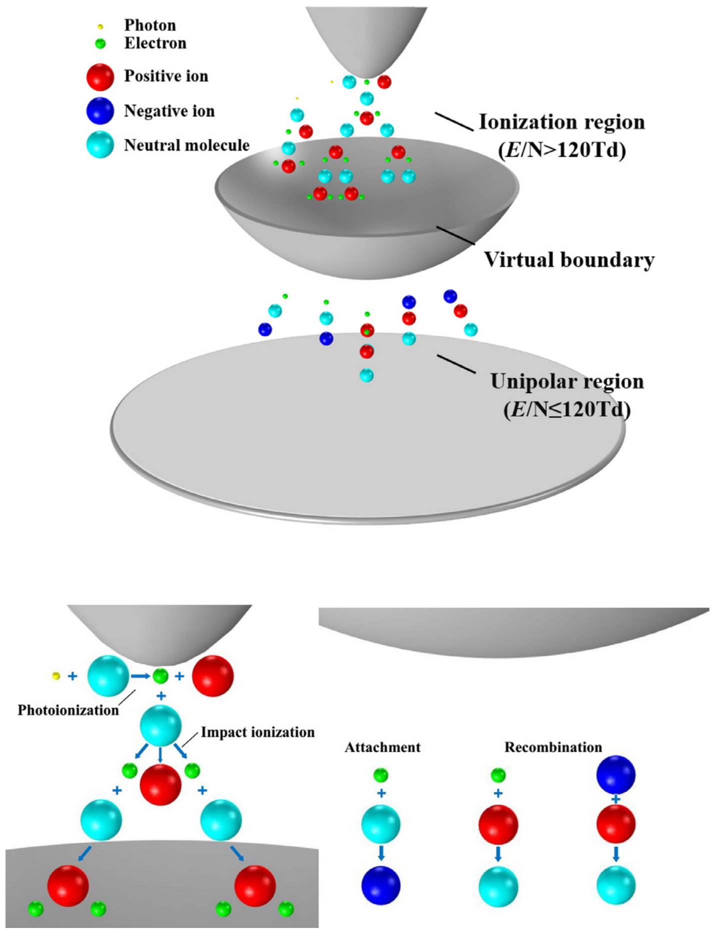

Fig. 1. Model of negative corona discharge.

by Sattari to solve the space charge density and he confirmed that the pulse frequency increases with applied voltage [14]. In addition, experimental method was utilized to verify the validity of the numerical simulation and a phenomenon was confirmed by semi-quantitative method that the number of UV photons varies with the applied voltage [15–17]. As for the photoionization term, the simplest model was built by uniform background ionization [18] while the integral model was utilized to calculate the photoionization term after that [19–22]. However, it is inevitable that this approach is time consuming and a huge computer memory is required. In order to solve this problem, efficient models of photoionization were presented by Bourdon et al using a set of three Helmholtz differential equations which were proved to be fast and accurate [23].

Electric field and ion distribution have a significant influence on the movement characteristics and removal efficiency of the particles in ESP. However, the ions produced by the corona discharge will charge the measuring instrument and have an effect on the accuracy and the distribution of electric field, so it is hard to measure the electric field and the charge distribution in ESP directly by instrument [24–28]. Consequently, numerical method was used to study the electric field distribution and the motion characteristics of the particles in ESP by McDonald who utilized finite-difference method to simulate the distribution of electric field in ESP [29]. Then the finite-difference method was developed by other scholars. This method made it feasible to simulate ESP with complex shapes [30–35]. The electric and flow field distribution in ESP were calculated using the finite element method by Davis et al, which fit well with the complex structure of ESP where triangular mesh was utilized [36–38]. Furthermore, the finite volume method was applied to simulate the removal efficiency of ESP by Schmid and the result was proved to be accurate by experiments. However, the charging characteristics and transient polarization process of the particles were not widely considered in negative corona discharge. In despite of the charging process in large time scale(such as second) or steady-state has been studied by many scholars, reconsideration about charging process of particles is required in nanosecond level.

The aim of this manuscript is to investigate the charging and motion characteristics of particles by combining corona discharge theory with transient equations, including equations of charging process of the particles and dynamic equations