Journal of Electrostatics 71 (2013) 815–822

Contents lists available at SciVerse ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

Effect of the experimental parameters on the number of free electrons in the drift region of a wire-cylinder electrostatic precipitator

Audrey Villot [a,]*, Yves Gonthier [b], Evelyne Gonze [b], Alain Bernis [b]

[a] UNAM Université, Ecole des Mines de Nantes, CNRS, GEPEA, UMR 6144, 4 rue Alfred Kastler, BP 20722 44307 Nantes cedex 03, France
[b] Université de Savoie, Polytec'Annecy-Chambéry, LOCIE, Campus Scientifique, Savoie Technolac, 73376 Le Bourget du Lac cedex, France

ARTICLE INFO

Article history:
Received 20 April 2012
Received in revised form
19 November 2012
Accepted 21 February 2013
Available online 13 March 2013

Keywords:
Corona discharge
Electrostatic precipitator
Free electrons
Gas electronegativity
Pressure
Temperature

ABSTRACT

The aim of this paper is to highlight the number evolution of free electrons in the drift region of a wire-cylinder electrostatic precipitator in negative voltage depends on the experimental parameters, more particularly of gas composition. A numerical model of the negative DC corona discharge developed by Chen et al. was used and modified to investigate the negative discharge corona for different gases. A parametric study was conducted to examine the effect on the electron distribution of operating conditions. The results showed the electron concentration increases with temperature, decreases when the pressure increases, and is closely related to gas composition.

1. Introduction

An electrostatic precipitator (ESP) is a filtration device comprising two electrodes with different curvature radii between which an electrical field is generated. The electric field, which is very intense near the electrode of the small curvature radius, decreases rapidly with distance. In the case of a wire-cylinder geometry, a high negative (or positive) voltage is applied to a wire placed at the center of the cylinder. The cylinder is grounded and used as a particle collector. When the potential difference applied between the two electrodes is sufficient, a corona discharge is formed around the wire. The development of corona discharge allows generating ions through electrical mechanisms of ionization, electron attachment and dissociation. These ions formed near the wire diffuse to the surface of the particles contained in the gas. Once charged, the particles undergo the impact of the electric field and drift toward the grounded electrode, where they are then collected.

There are several parameters which can influence the ESP functioning and to link them to each others can be complex. The gas composition, its temperature and pressure, the presence of particles are so many parameters that can impact the discharge phenomena and ionization gas. The gas ionization produces itself an ions stream around the active electrode, also called “electronic wind”, that disrupts locally the velocity field of the gas. Thus, the electric field is disturbed by space charge and ionic particles. To find the optimal working conditions of an ESP, it is possible to use the current–voltage curve. This curve is limited by two points: the corona onset voltage and the spark-over (Fig. 1). When the voltage applied exceeds a distinct value, an electrical current between the two electrodes can be measured, indicating the corona onset voltage, and a colored sheath appears around the low radius of curvature electrode. The colored sheath corresponds to the gas ionization area. The corona sheath radius increases when the voltage applied is increased until it reaches the spark-over, which marks the electrical breakdown of the gas. This curve depends on several parameters, the most important of which are temperature, pressure, gas composition, and ESP geometry.

The main equations making the calculation of these characteristics are the Maxwell equations, most particularly the Poisson equation of electric potential, and the electric-current continuity equation. In the literature, four methods to solve these equations have been advanced: finite differences [1–3], finite elements [4–6], the method of characteristics [6], and finite volumes [5]. To solve Maxwell equations, several authors assume that the inter-electrode space is divided into two areas [1,4,7]: the ionization area, near the active electrode where the ions are produced, and the attachment

---

* Corresponding author. Tel.: +33 251 858 277.
E-mail address: Audrey.villot@mines-nantes.fr (A. Villot).

0304-3886/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.elstat.2013.02.004

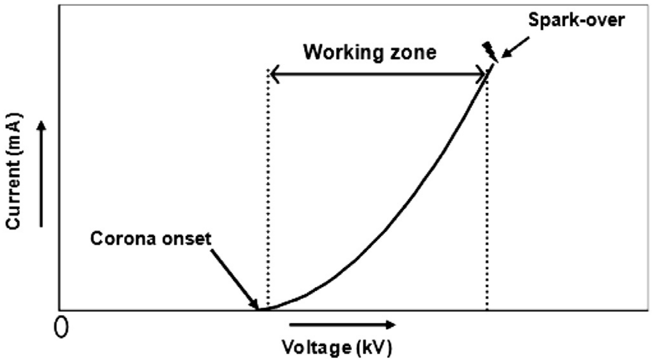

Fig. 1. Typical current–voltage curve.

area. It is very difficult to model the ionization area, so it is often ignored in favor of the attachment area where Maxwell equations are used [8]. Consequently, this method only takes into account the current that results from the movement of negative ions produced by electron attachment or dissociation. This assumption is not always confirmed. Indeed, with this method it is possible to observe differences between experimental results and mathematical values in particular cases. This difference was explained by White [9], Sigmond [10] and then by Ferreira et al. [11], who ascribe it to the presence of free electrons in the interelectrode space. The presence of free electrons was observed strictly in negative voltage when the interelectrode distance is less than 1.5 cm [12].

Even if the electron concentration remains relatively low compared with that of the ions, their effect is not negligible because of their high electrical mobility, which is about 10,000 times greater than that of ions [10]. The fraction of the electronic current in comparison with the ionic current depends on the ESP operating conditions. When the temperature increases, the electron attachment on gas molecules decreases and therefore the number of free electrons increases [13]. Conversely, when the pressure increases, the number of free electrons decreases [14].

The free electron role on the filtration is not well determined for the moment. Dubard et al. [12] introduced only the fact that the free electrons would be more efficient on the filtration of the small particles (less 1–2 μm) than the ions. Thus, the presence of free electrons could increase the electrostatic precipitator global efficiency.

The purpose of this paper is to highlight that the presence of free electrons in the drift area depends on experimental parameters, more particularly of gas composition. The study of the evolution of free electron concentration in the drift region was conducted using the negative corona discharge model developed by Chen et al. [15,16]. The model proposed describes the electric charge carrier evolution (ions and electrons) in the interelectrode space as a function of the current value set, the temperature, and the air pressure. We modified this model to study the negative discharge corona with different gas compositions.

2. Description of the negative DC corona discharge

Fig. 2 describes the phenomena that lead to the development of a negative corona discharge for a wire-cylinder geometry. The central electrode is supplied with a high negative voltage and the outer cylinder is grounded.

The corona discharge is initiated when the electric field near the central electrode (the wire) is sufficient to ionize the surrounding gaseous species. The minimum electric field (E_0) is a function of the wire radius, the wire surface roughness, gas temperature, pressure, and composition. Negative corona discharge is only possible in electronegative gases such as oxygen, water vapor, and carbon dioxide. It does not occur in the pure gases such as nitrogen, helium, and argon, which have no affinity for electrons.

The negative corona discharge grows from the cathode (the wire) to the anode (the outer cylinder). Primary electrons, produced near the cathode generate secondary electrons that will lead to the formation of positive and negative ions in their collisions with gas molecules. These secondary electrons are produced either by photoemission from the central electrode or by bombardment of the central electrode by positive ions or even by gas photo ionization. As and when the electrons move away from the central electrode, they become less active due to the decrease in the electric field. Thus, the ionization mechanisms are gradually replaced by recombination and electron attachment mechanisms.

In negative corona discharge, the recombination mechanisms with positive ions can be ignored. Therefore, the electron production only competes with the electron attachment phenomena which lead to the formation of negative ions. Near the cathode, ionization is the main mechanism and the production of electrons is dominant. The radius at which the ionization rate equals that of recombination defines the boundary of the ionization area. It is generally accepted that this boundary is the radius at which the reduced electric field (E/N) is 120 Td [17]. The reduced electric field is defined as the ratio of the electric field (E) and the number of gas molecules per cubic meter (N) expressed in Townsend ($1\ \text{Td} = 10^{-21}\ \text{V m}^2$). Beyond this boundary, the electron attachment mechanisms are dominant and the electron number decreases gradually with distance. However, the electrons coming from the ionization area still have enough energy to cause reactions with gas molecules, until a certain distance from the central electrode is reached. Thus, the corona plasma region extends beyond the ionization region. In this study, the plasma boundary is defined as the radius at which the reduced electric field equals 80 Td [16]. At this value, the mean kinetic energy of the electrons is 1.85 eV and some electrons are energetic enough to participate in electron-impact reactions.

It is generally accepted that the drift region is a monopolar area consisting only of ions whose polarity is identical to that of the electrode with a small radius of curvature. However, in some cases, only in negative corona discharge, it is possible to observe the presence of free electrons in the drift region. The idea that free electrons can be present in the drift area with negative corona discharge was introduced by White [9], then by Sigmond et al. [10] and Ferreira et al. [11].

3. Description of the negative DC corona discharge model

The aim of this paper being to underline to the presence of free electrons in the drift region of an ESP depends on experimental parameters, in particular the gas composition. It is for that the negative corona discharge modeling was used with a wire-cylinder ESP (20 mm in diameter, 270 mm in length).

3.1. Assumptions

The model of the negative DC corona discharge makes it possible to determine the electrical charge carrier distribution inside the interelectrode space as well as the electric field distribution. To develop their model, Chen et al. [15,16] put forward the following assumptions:

- The ionization area along the wire is homogenous, which is not completely true. Indeed, at a voltage near the corona onset voltage, only discrete points or tufts appear. They are irregularly spaced along the wire and preferentially appear as imperfections