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An experimental study of relative humidity and air flow effects on positive and negative corona discharges in a corona-needle charger

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ABSTRACT

In this paper, the effects of inlet air RH and air flow rate on positive and negative corona discharges in a corona-needle charger have been experimentally studied and discussed. Its corona discharge characterizations in terms of current-to-voltage relationships of the corona-needle charger on the effects of inlet air RH and air flow rate were evaluated at applied corona voltages between 0 and 3.1 kV, an air flow rates between 5 and 15 L/min, a relative humidity between 20 and 90%, and an operating pressure of about 101.3 kPa. Experimental results were shown that discharge current is strongly affected by the RH level of the inlet air. The positive discharge current was found to be decreased with increasing RH value at RH values below 60% and increased with increasing RH value at RH value above 60% in the same corona voltage. The negative discharge current was found to be stable with increasing RH value at RH values below 40% and increased with increasing RH value at RH value above 40% in the same corona voltage. For the air flow rate effects, the positive discharge current was found to slightly decrease when the air flow rate increased at RH value below 90% and to increase with the air flow rate at RH value of 90%. For the negative corona, the discharge current was also found to monotonically decrease when the air flow rate increased.

1. Introduction

Producing unipolar ions by corona discharging has been applied successfully in unipolar aerosol charging and several designs of aerosol corona charger have been employed and described in the published literature [1]. Unipolar aerosol corona chargers have been widely used in the measurement of aerosol particle charge based on unipolar corona charging and electrostatic detection of charged aerosol particles such as the electrical aerosol detector. This is because of its simplicity and capacity to provide high concentration of ions [2]. A typical electrical aerosol detector consists of two key components, one for unipolar aerosol charging and the other for measuring the electric current on charged aerosol with an electrometer. The output signal of an electrometer depends strongly on the particle charging technique used [3]. However, the detector was very stable at relative humidity (RH) values below 60% but the detector zero reading starts to drift away from the manufacturers expected stable value at RH higher than 60%. This makes the detector unstable, its output unreliable and a strong indication that the detector is not suitable for use under inlet air RH of above 60% such as ambient atmospheric conditions, water content of ambient aerosol particles is usually to be below and above 60% [4]. Placing some silica gel dryer or dehumidifier before enter the detector however reduced the drift, allowing its use under conditions of over 60% RH.

In the aerosol particle charging by corona discharge, the air RH had significant effects on both positive and negative corona discharges and electrostatic characteristics of the charger. Corona discharge is a gas discharge phenomenon and it is influenced by many factors, including air humidity and temperature. At higher RH, the adsorption of water on the surface of a particle will have a significant impact on the corona onset electric field, the electric conductivity enhancement and electrical mobility of ions. The corona onset electric field decreased with the increase of air RH [5–8]. Back in 1920, Peek proposed his well-known empirical

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equation for evaluating the corona onset electric field on conductors [9,10]. This equation included the influence of temperature and pressure, but the effect of air humidity was ignored. Many researchers numerically studied the distribution of electric filed and charge density in electrostatic precipitators (ESPs) [11,12]. Peek equation was used in these studies, which considered the effects of temperature and pressure. But the effect of air RH was not included in these studies. A few modified Peek formulas were suggested to account for the effect of air RH [12,13]. Previous theoretically and experimentally studies, investigating the effect of RH on the electrostatic aerosol charge and on current-to-voltage characteristics have been numerous studied in the past several decades [5–18]. For instance, Young et al. [14] was studied the influence of RH on the electrostatic charge and aerosol performance of dry powder inhaler carrier based systems. The authors reported in this paper that increased storage RH resulted in a reduction in net charge to mass ratio with the greatest reduction at RH >60%. Higher RH would allow a greater degree of electron mobility and thus reduce the charging mechanism. Fouad and Elhazek [7] was studied the effect of humidity on positive corona discharge in a three electrode system. The authors reported in this paper that the corona inception voltage increases as the air relative humidity increases up to a certain limit after which the corona inception voltage begins to decrease with increasing air relative humidity. It is also found that the increase of air relative humidity favors the positive glow formation and affects its stability. Nouria et al. [11] was characterized the behavior of DC corona discharge in wire-to-plane ESPs as influenced by the RH of the inlet air. The authors reported in this paper that discharge current is strongly affected by the RH level of the inlet air. The time-averaged current is lower at higher RH for a given voltage, except when RH of 99%. Time evolution of the discharge current is affected by the RH especially in the case of negative corona. Above various works have been experimentally and theoretically presented the effect of air RH on both positive and negative corona discharges for larger voltage range in various electrode geometries such as the wire-to-cylinder, the wire-to-plane, needle-to-plane and the point-to-plane, but was not have taken in the needle-to-nozzle electrode geometry and was also not introduced explicitly the dependence of the air flow rate in these studies. Since the geometrical configuration of electrodes of the corona-needle charger is similar to the needle-to-nozzle electrode geometry, a coaxial needle electrode placed along the axis of a cylindrical tube with tapered ends, and the corona voltage was applied only within a narrow range, typically 2.5–3.5 kV. Therefore, the effect of inlet air RH and air flow rate on positive and negative corona discharges in a corona-needle charger has not been extensively studied for a narrow voltage range in previous work and literature. The knowledge of the inlet air RH and air flow effects on positive and negative corona discharge behavior in the corona-needle charger is of crucial important for measuring water content of ambient aerosol particle charge by the electrical aerosol detector in ambient atmospheric conditions. Some aspect of this effect require further investigations in order to validate a realistic mathematical model of the physical phenomena, as an essential step towards the accurate numerical simulation of the aerosol particles charging by corona discharge.

The aim of the present paper is to experimentally study the effects of inlet air RH and air flow rate on positive and negative corona discharges in a corona-needle charger. Its corona discharge characterizations in terms of current-to-voltage relationships of the corona-needle charger on the effects of inlet air RH and air flow rate were experimentally studied and discussed at applied corona voltages between 0 and 3.1 kV, an air flow rates between 5 and 15 L/min, a relative humidity between 20 and 90%, and an operating pressure of about 101.3 kPa.

2. Description of corona-needle charger

The schematic diagram of the corona-needle charger used to evaluate the relative humidity and air flow effects in this study is shown in Fig. 1. The corona-needle charger's geometrical configuration is similar to the corona-needle charger used by Intra and Tippayawong [19,20]. The present charger consists essentially of a coaxial needle electrode placed along the axis of a cylindrical tube with tapered end, and divided into three sections. The first and second sections (from top to bottom in the drawing) are made of a polytetrafluoroethylene (PTFE), and the third (outlet section) of stainless steel tube. The PTFE tube is an electrical insulator between needle electrode and outer electrode and served to hold the needle electrode coaxial with the outer electrode. The needle electrode could be screwed into the PTFE insulator to connect to a DC high voltage supply, typically in the range between 2.7 and 3.0 kV. The needle electrode is made of a stainless steel rod, 3 mm in diameter, ending in a sharp tip. The needle electrode was polished to an extremely fine surface finish to avoid undesirable electric field effect on particle motion due to non-uniform electric field which results from small surface scratches and imperfections. The tip radius is about 50 μm, as estimated under a microscope. The needle cone angle is about 10°. The diameter of the outer electrode is 20 mm, its length is 20 mm with conical shape. The orifice diameter is about 3.5 mm. The distance between the needle electrode and the cone apex is 1.75 mm. The needle electrode head is connected to a positive and negative high voltage, while the outer electrode is grounded.

3. Corona current and discharge in humid air

In the absence of aerosol particles, Townsend derived an equation to characterize the DC steady corona current–voltage relationship for point-to-plane geometry is given by Ref. [21].

$$I = AV(V - V_o) \quad (1)$$

where I is the corona discharge current, V is the applied voltage, V_o is the corona onset voltage and A is the dimensional constant depending on the inter-electrode distance, the needle electrode

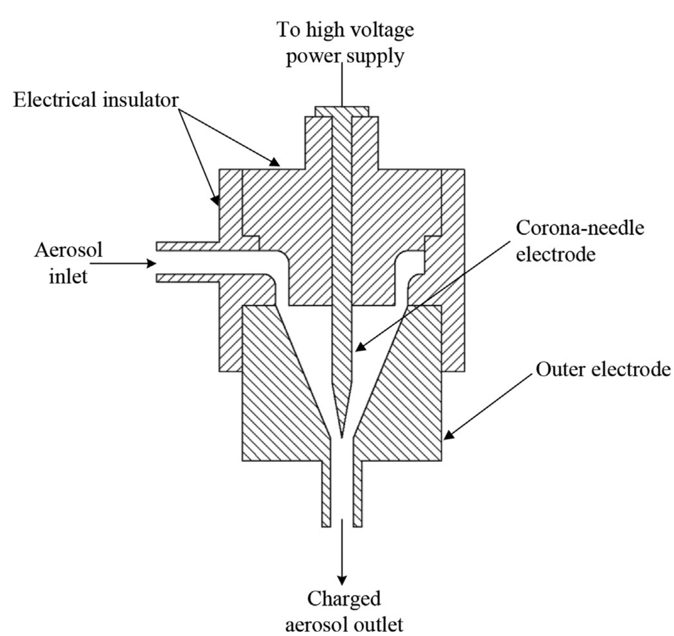

Fig. 1. Schematic diagram of the corona-needle charger.