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Effect of cylinder electrode arrangement on the ionic wind properties of needle–cylinder electrodes

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ABSTRACT

Needle–cylinder electrodes designed to generate ionic wind have been explored experimentally. The increase of the gap distance between needle and cylinder from 4 mm to 16 mm cause an increase of the ionic wind velocity from 1.1 m/s to 2.46 m/s. The opposite behavior was observed when this distance lengthened from 18 to 28 mm. At the same time, a step voltage was used to increase the ionic wind velocity up to 3.6 m/s. These results indicate that electrode arrangement is very important to maximize the ionic wind velocity.

1. Introduction

As early as the nineteenth century, ionic wind (also known as electrohydrodynamic flow), which is usually generated between sharp and blunt electrodes, was first investigated. There are many types of discharge electrodes that can be used to produce ionic wind, including wire–rod, needle–mesh, wire–cylinder, and needle–cylinder [1–4]. In recent years, numerous researchers have worked on applying ionic wind to different applications such as electric propulsion, air filters, ion drag pumps, aerodynamics, and heat transfer [5–8]. With the development of ionic wind applications, many efforts have been made to increase the velocity of ionic wind. Qiu et al. produced a serial-stage needle–mesh gas pump that achieved an ionic wind velocity of 7.39 m/s by combining four stages [2]. It was later demonstrated that 25 stages connected in series with alternating positive and negative stages increased the ionic wind velocity up to 16.1 m/s [9]. Rickard and colleagues used seven-stage needle–ring electrodes to generate ionic wind faster than 7 m/s [10].

Many attempts have been made to develop wire–cylinder electrodes because they can generate a stable discharge. For example, a detailed analysis of the wire and cylinder geometry to optimize parameters was conducted by Komeili and co-workers [11]. More recently, Colas et al. generated ionic wind using a wire–cylinder–plate system [12]. This system included two parts: a wire–cylinder electrode designed as the ionization zone, and a cylinder–plate electrode as the accelerating zone, which can greatly increase the ionic wind velocity. On the basis of these experiments, Martins simulated wire–cylinder–plate and wire–cylinder–cylinder systems using COMSOL software, also revealing that the accelerating zone is helpful to increase ionic wind velocity [13]. Recently, wire–single cylinder, wire–double cylinder and wire–cylinder–cylinder electrodes were designed and compared [14]. These experiments demonstrated that several cylinder electrodes are favorable to increase ionic wind velocity.

Although a wire–cylinder electrode can efficiently generate an ionic wind, there are still arc discharges when the electrode parameters are not suitable [11]. In comparison, a needle cathode electrode is more stable because the needle tip is only a few micrometers in diameter and the asymmetric electrical field is apparent [15]. Another major limitation of present research on wire–cylinder electrodes is that the effect of the number and arrangement of cylinder electrodes on ionic wind properties is not clear. In Ref. [14], the anode was one or two cylinders. The effect of three or more cylinder electrodes on ionic wind generation has not

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yet been explored.

In view of the limitations of existing wire–cylinder–cylinder electrodes, here we study the effects of cylinder number and arrangement on ionic wind velocity. We design needle–cylinder structures that can achieve stable corona and glow discharges, which may be used as an ion source in analytical instrument [16–18].

2. Experimental set-up

The experimental set-up was designed to observe different discharge modes and the relationship between the cylinder number and ionic wind velocity of the systems. Discharge was produced between a needle and one or several cylinder electrodes, as shown in Fig. 1. The needle was welded to a circuit board and the circuit board was fixed to a frame by screws. The frame was made of Plexiglass to provide electric insulation and transparency so that the discharge process could be observed.

Ionic wind is based on negative air discharge. Thus, discharge stability is very important to achieve ionic wind. To realize stable air discharge, a discharge circuit was designed. A schematic diagram of the discharge is illustrated in Fig. 2. The discharge circuit included a DC power supply (Hengbo, HB-Z202-300AC) and ballast resistor. The discharge was powered by a DC power supply (0~−20 kV, 100 W). A ballast resistor (12 MΩ) was connected to the cathode to restrict the discharge current (I). A test resistor (1 kΩ) converted I into a voltage, which was measured by an oscilloscope (Tektronix) and digital multimeter. The oscilloscope was used to observe and record the actual AC discharge voltage, while the digital multimeter specifically measured the effective voltage.

The discharge electrode was a needle–cylinder electrode. The needle had a sharp tip with a diameter of 27 μm, and the copper cylinder had a diameter of 4 mm and length of 60 mm. The distance between the needle and cylinder was adjusted by fixing the needle in different holes in the frame.

In the experiments, the needle serving as the cathode was connected to the negative terminal of a high-voltage power supply. The ground electrode (cylinder) was connected to the ground, and then ionic wind flow was induced from the needle to the ground electrode. The ionic wind velocity was measured with an anemometer (Testo 405-V1). The vertical distance between needle and cylinder electrodes was fixed at $d = 10$ mm, as shown in Fig. 2.

The horizontal distance between needle and cylinder l was adjusted between 4 and 28 mm in increments of 2 mm by inserting the cylinders into different holes in the frame (inner diameter: 30 mm). The measurement range and sensitivity of the anemometer were 0–10 and 0.01 m/s, respectively. Ionic wind velocities in the core area were measured at a distance of 2 mm from the tube outlet. Discharge images were recorded by a digital camera (Canon EOS 60D). All experiments were conducted at atmospheric pressure and room temperature (23 °C). The related geometrical dimensions and parameters used in the experiments are listed in Table 1.

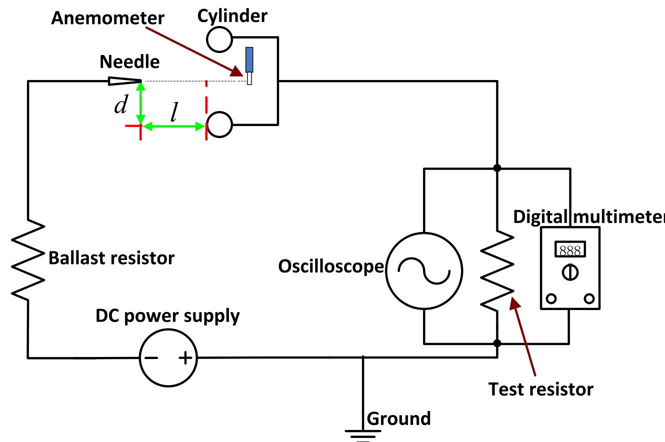

Fig. 2. Electrical circuit of the needle–cylinder electrode set-up.

3. Results and discussion

3.1. Influence of needle–cylinder distance on ionic wind velocity

In this work, the goal was to study the influence of l on the ionic wind velocity of the electrode set-up. The needle was fixed, and l

Table 1
Geometrical dimensions and parameters of the needle–cylinder electrode set-up.

Parameter	Dimension
Applied voltage	−12 kV
Gap distance between electrodes	4,8,10,12,14,16,18,20,22,24,26,28 mm
The radius of needle tip	20 μm
The diameter of cylinder	4 mm
The length of cylinder	60 mm
The ballast resistor	12 MΩ
The test resistor	1 kΩ
The inner diameter of frame	30 mm
The length of frame	46.5 mm

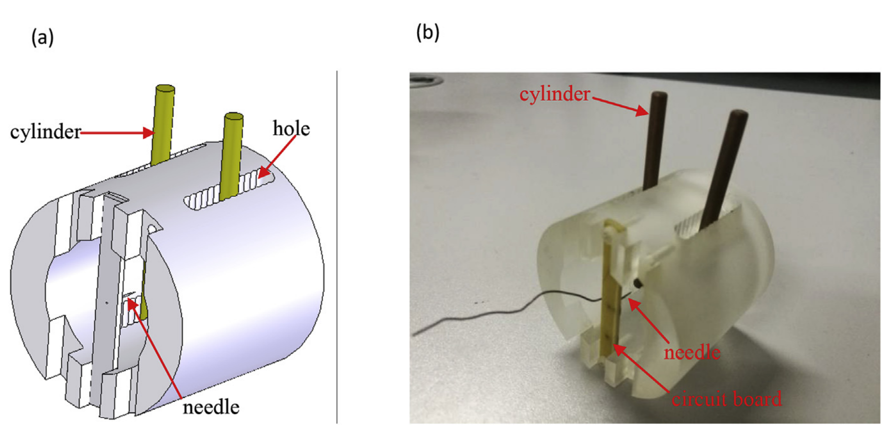

Fig. 1. The schematic diagram of the experimental set-up (a) Schematic diagram of the experimental set-up. (b) Photograph of the experimental set-up.