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Velocity and energy conversion efficiency characteristics of ionic wind generator in a multistage configuration

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ABSTRACT

This paper reports the experimental and theoretical analysis of the ionic wind velocity and electrical-to-kinetic energy conversion efficiency in an ionic wind generator with six stages in series. Each stage contained a pair of cylindrical multipin-to-ring electrodes. The experiments were carried out in a negative dc corona discharge and the experimental results showed that both the velocity and efficiency are proportional to the square root of the number of stages. The efficiency was found to be proportional to the wind velocity within the experimental range. It was also confirmed that the wind velocity is proportional to the square root of the current and a linear function of voltage. Approximately 1.0% conversion efficiency and stable volumetric flow of more than 2000 L/min were achieved experimentally.

1. Introduction

In a pin-to-plate corona discharge configuration supplied with a high dc voltage, gas molecules near the tip of the pin are ionized by the very high electric field intensity at that point. Ions acquire momentum from the electric field due to Coulombic forces, subsequently transferring them to the surrounding gas molecules [1]. This momentum transfer results in the movement of gas from the pin to the plate, which is called an ionic wind (also called an electric wind or gas-phase EHD flow) [1].

Ionic winds have a wide variety of application potentials such as electrohydrodynamic enhancement of heat transfer [2–4], flow control [5–11], micro-scale mechanisms [12,13] and even in food industry [14]. The ionic wind velocity approximately is a linear function of voltage, and is proportional to the square root of the current [15] while the conversion efficiency increases as the neutral fluid velocity increases [16].

There have been continuous investigations to characterize the ionic wind for the various electrode configurations. Robinson showed 3.0 m/s of ionic wind velocity for a single blower with approximately 1% energy conversion efficiency in a pin-to-mesh electrode configuration with 70 mm of tube diameter [15]. Moreau and Touchard's experimental investigation of both pin-to-mesh and pin-to-ring configuration with 20 mm tube resulted in a maximum velocity of 10 m/s and an efficiency of about 1% [17]. Jewell-Larsen et al. optimized a single electrostatic fluid accelerator with a sharp edge-to-parallel electrode geometry to achieve a significant improvement in air velocity, reaching a maximum velocity of 4 m/s [18]. They showed that their prototype efficiency was comparable to that of conventional rotary computer cooling fans at lower air velocities [18]. Recently, as the special geometries, wire-rod geometry was characterized by Komeili et al. [19] and wire-non-parallel plate geometry was characterized by Tsubone et al. [1].

On the other hands, some efforts have been made to increase the ionic wind velocity by stacking several unit generators in series. Robinson showed that five blowers assembled in series resulted in 3.5 m/s of ionic wind velocity in a pin-to-mesh electrode configuration [15]. Recently, Rickard et al. constructed a seven stage configuration to maximize the ionic wind velocity, wherein each stage was made from a single pin-to-cylindrical ring electrode with 25.4 mm of tube diameter, and reported a conversion efficiency of 0.1% and the maximum velocity of 7 m/s with a converging nozzle at the exit [20]. Rickard et al.'s experimental results showed an improvement in efficiency in a two blower stack in series but no further improvement from a three to seven blower stack [20]. However, there are no reports of a further systematic study of the stacking characteristics of velocity and efficiency.

In this paper, an ionic wind generator with six stages, each consisting of an inner ring electrode with multipins (cathode) and

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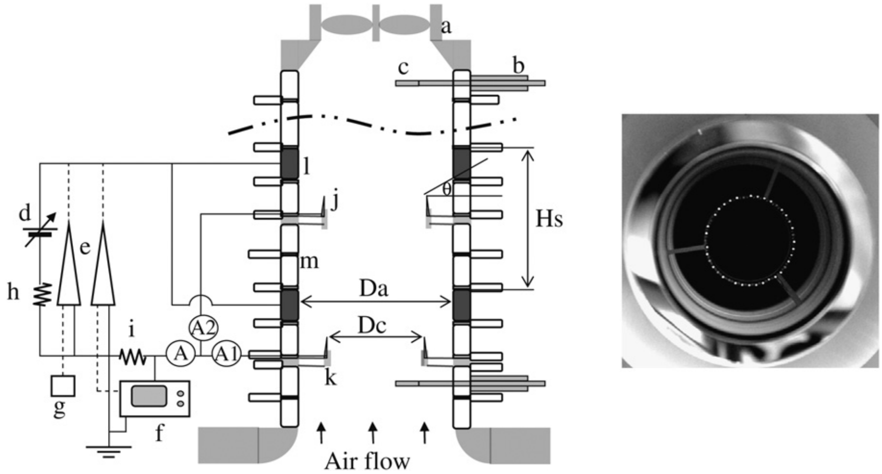

Fig. 1. Left: Schematic diagram of the experimental set-up of the cylindrical ionic wind generator. Details of only 2 bottom stages are shown. Right: Photo of discharging multipins taken from the top side. A: moving-coil type current-meter measuring total current. A1, A2: moving-coil type current meters monitoring the currents of both stages. a: vane anemometer. b: hot-wire anemometer. c: sensor of hot-wire anemometer. d: dc power supply. e: high voltage probes. f: storage oscilloscope. g: multimeter measuring high voltage. h: limiting resistance (2.5 MΩ). i: shunt resistance (1 KΩ). j: cathode ring with 40 pins. k: cathode holder having three thin bridges. l: anode ring. m: flow guide wall. θ: tilted angle (40°). Hs: height of unit stage (115 mm). Da: inner diameter of anode ring (78 mm). Dc: outer diameter of cathode ring (40 mm).

an outer ring electrode (anode), was set-up in order to investigate the stacking characteristics of ionic wind velocity and its energy conversion efficiency. The ring diameter was selected to reduce the air flow resistance and multipins were introduced to obtain as high a current as possible. At first, the basic performance, and subsequently the stacking characteristics of the ionic wind generator were examined experimentally. In addition, explicit equations describing the stacking characteristics were developed based on the empirical current–voltage and velocity–current relations.

2. Experimental set-up and measurements

Fig. 1 shows a schematic diagram of the experimental set-up of the ionic wind generator with six stages. Each stage consisted of a stripped stainless ring electrode (outer diameter: 40 mm, thickness: 0.5 mm, pin height: 5 mm, ring height: 10 mm) with saw-tooth shaped pins on the upper side and another stainless ring electrode (inner diameter: 78 mm, thickness: 10 mm, height: 25 mm). The pins were machined by wire electrical discharge. As shown in Fig. 2, the inner and outer ring electrodes were used as the cathode and anode, respectively. The outer ring had 20 mm of radius of curvature on the inner bottom edge and other three edges had 2 mm of radius of curvature. The line connecting the bottom of the outer ring and the pin tip made an angle of 40° with respect to the horizontal line. Glass fiber enforced epoxy was used as an insulating material for the flow guide wall. The structure of the multipin-to-ring electrode for a unit stage was determined by trial and error to achieve the highest breakdown (spark initiation) voltage before stacking. Three cathode rings (40, 100, and 200 pins) were tested before starting the main experiments. All rings showed a similar current and voltage performance. The 40 pin cathode ring was chosen for the six stage configuration because it was easier to machine with uniformity than the others.

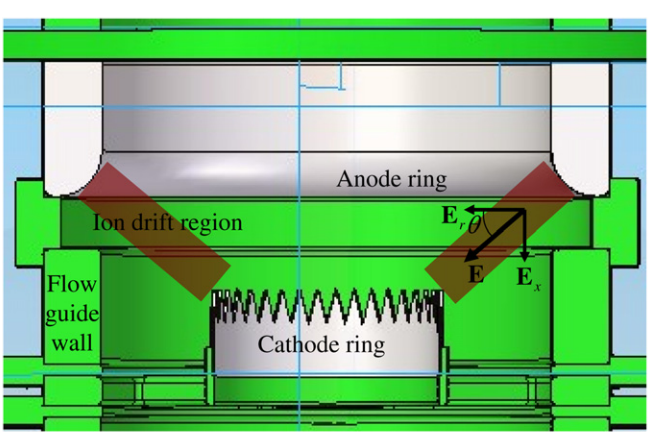

Fig. 2. Schematic of simplified electric field configuration in the ion drift region. Rectangular region between anode ring and cathode ring represents 1 dimensional unipolar ion drift region.

A dc power supply was constructed using a full-wave rectification circuit consisting of a high voltage transformer (220 V → 25 kV, 150 W), high voltage diodes for rectification, and high voltage capacitors for smoothing the output voltage wave. Two units of power supply were connected in series to generate a maximum dc voltage of 50 kV. Stable operation was achieved up to 40 kV of dc output voltage and 100 W of power consumption by the ionic wind generator. The ripple rate was kept below 3%. The negative dc voltage was grounded and supplied to the cathode pin side. A positive polarity with a high voltage was connected to the anode rings. The surge current caused by breakdown was suppressed by the limiting resistance of 2.5 MΩ. Two high voltage probes with 1000:1 attenuation were used; one for a storage oscilloscope to monitor the voltage wave form and the other for the multimeter to measure the high voltage. The total current and current flowing through each stage were measured and monitored using moving-coil type dc ampere meters. At the same time, current wave forms were monitored using a storage oscilloscope by detecting the voltage drop in the shunt resistance. The absolute values of the high voltages read from the multimeter and oscilloscope were cross-checked, while the current values from the dc ampere meters and oscilloscope were compared with each other.

Exit velocities were measured by hot-wire anemometer and vane anemometer for the purpose of cross-check. The hot-wire anemometer was horizontally located 34 mm above the top anode ring. Measurements were made at the points after every 2 mm horizontal movement of the hot-wire anemometer. 30 s of waiting time was enough for the saturation of indicated value. The average