A STUDY OF ION WIND GENERATOR USING PARALLEL ARRANGED ELECTRODE CONFIGURATION FOR CENTRIFUGAL FLOW MIXER

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ABSTRACT

Ion wind is recently applied in various research areas such as the biomedical engineering, microfluidic mixing and particle manipulation. In this work, a bipolar ion wind generator configured by parallel arranged electrodes is used for centrifugal mixing applications. With the proposed configuration, negative and positive ion winds are simultaneously generated, mixed and then neutralized by each other while travelling toward liquid surface. The efficiency of the device was investigated both computationally and experimentally. The mixing of liquid occurred in different ways when the system is activated by either direct or alternating currents. Furthermore, the mixing is dependent on the dimension of electrode tip.

KEYWORDS: Flow mixer, ion wind, parallel arranged

INTRODUCTION

Centrifugal flow, a potential technique to enhance the mixing, is an efficient way for inertial sensing [1]–[4]. Several promising techniques to create vortex flow have been reported, such as ion wind [5]–[9] or PZT diaphragm [10]–[14]. Recently, ion wind has been applied in various research areas such as the biomedical engineering, microfluidic mixing and particle manipulation because of the outperformed features of ion wind based devices including neat dimension and low energy consummation. For example, swirl flow by ion wind significantly increases the concentration of biological samples while shortening the cultivation time [5] [15]. In such systems, ion wind configuration is unipolar while the liquid is a part of the high voltage electric circuit. Therefore, strongly reactive ions can penetrate into the liquid, yielding a change of its composition [16].

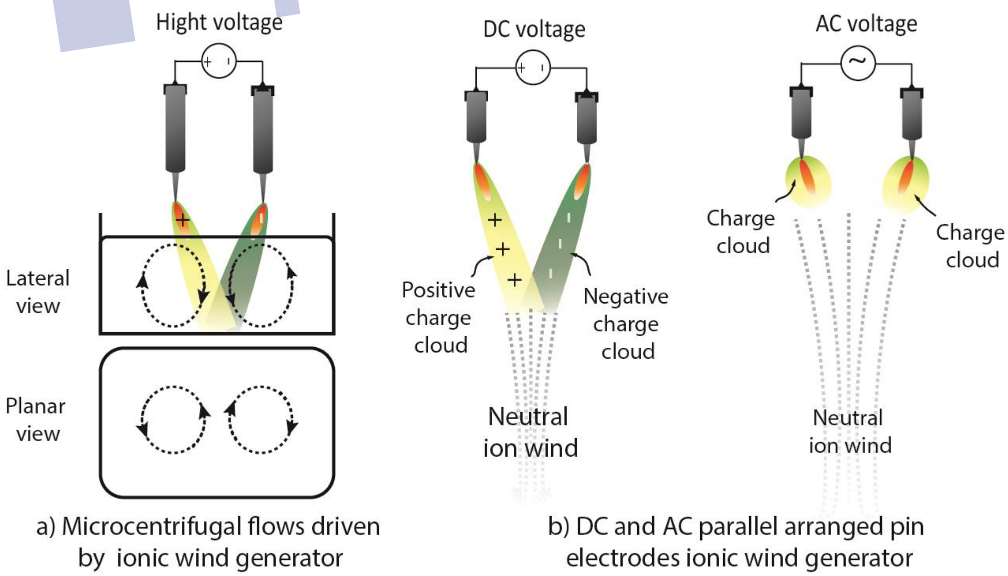


Figure 1. Point-to-point configuration based ion wind generation for mixing purpose.

In this work, a bipolar ion wind generator configured by parallel arranged electrodes is used for centrifugal mixing applications. Negative and positive ion winds are simultaneously generated, mixed and then neutralized by each other while travelling toward liquid surface as described in Figure 1. The mutual impact of ion winds and the liquid surface yields series of micro vortexes in the liquid and then strengthens the mixing process (see Figure 1a). The mixing process of liquid by the present ion wind based system using the direct current (DC) or alternating current (AC) will be studied and evaluated by numerical and experimental works.

NUMERICAL ANALYSIS

Numerical simulations were conducted to illustrate the effect of space charge on the properties of ion winds with details in [17]–[20]. The numerical simulation of a 3D transient model using OpenFOAM, by Figure 2 shows that ion winds are generated and well mixed together at a short distance from the electrode tip. The result in Figure 2a demonstrates that the total ion cloud by AC source is symmetry and has no residual charge. Simulated results also reveal an enhancement of the electric field through the transition of charge polarity, i.e. while the positive charge moves away from the probe, the opposite charge reaches to the probe [18]. This enhancement is gradually decreasing with time because of the charge dissipation in the electrode interspace. For the steady state, with a maximum ion wind velocity of 1.5 m/s, it takes at least 0.36ms for ion wind to reach the probe, which is out of the presented time scale. Meanwhile, ion wind generated by DC using different tip shapes is bent toward the electrode of larger tip diameter as shown in Figure 2b. In fact, ion wind by the tip electrode of 15μm is stronger and hence, the merging ion wind is deflected towards the tip electrode of 80μm.

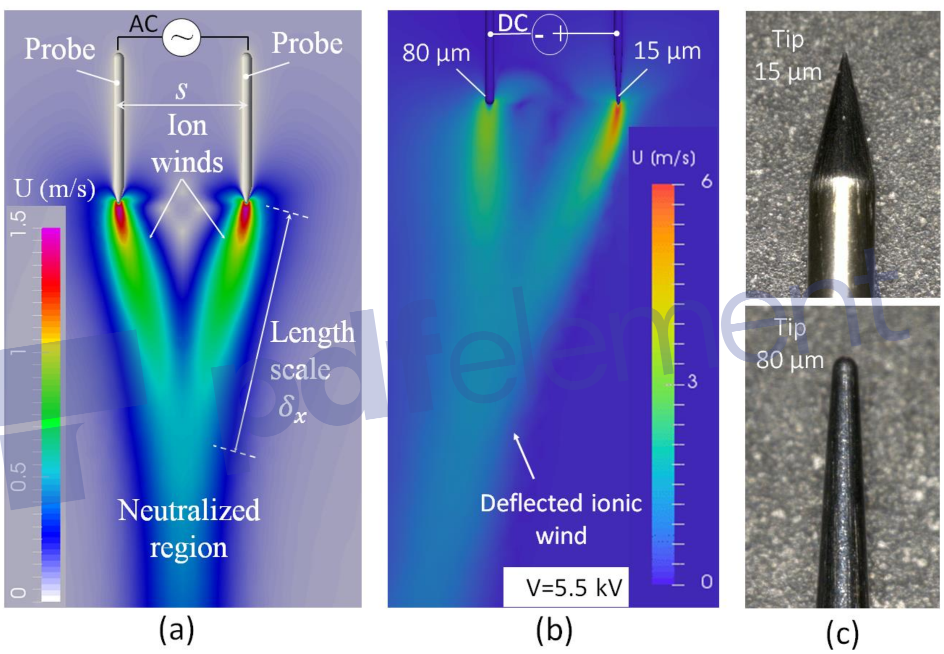
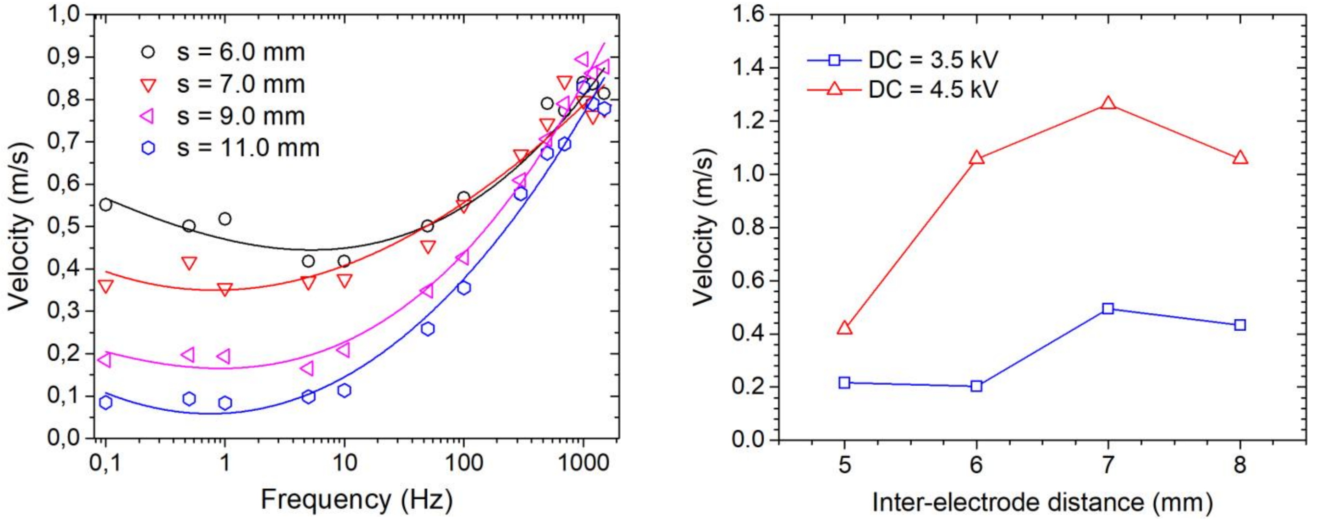


Figure 2. Numerical simulation: Ion winds by AC (a) and DC corona (b); Photos of electrodes with tip diameters of 15 µm and 80 µm.

EXPERIMENTAL RESULTS AND DISCUSSIONS

An ion wind generator uses two stainless steel electrodes of 8 mm length and 0.4 mm diameter arranged in parallel with each other. The electrodes are connected to a high voltage. A thermal anemometer (ISA-90N) installed L = 25 mm downstream of the device to monitor the ion wind velocity is placed in the vertical plane with a distance of 25 mm away from the electrode tip. In this plane, the anemometer located at the same height of the electrodes is thoroughly adjusted to a suitable position on its plane to obtain the measured peak velocity.

For the DC corona system, the configuration includes an electrode with tip diameter of 15 µm and another one with tip diameter of 80 µm. The inter-electrode distance *s* is changeable using a three-axis movable stage. Experimental results show an average jet flow velocity up to 1.25 m/s is achieved with inter-electrode distance of 7 mm using an DC voltage of 4.5 kV (Figure 3b), or by an AC voltage of 4.0 kV with the frequency of 1000 Hz (Figure 3a). Results also reveal that for a relevant frequency, ion wind by the AC system is much stronger with a given geometrical configuration of electrodes. The experimental finding is in a good agreement with one by the aforementioned simulation.



(a) (b)

Figure 3. Experimental results. (a) AC corona ion wind velocity versus the frequency with 4 kV square wave. (b) DC ion wind velocity versus the inter-electrode distance for different discharge voltages.

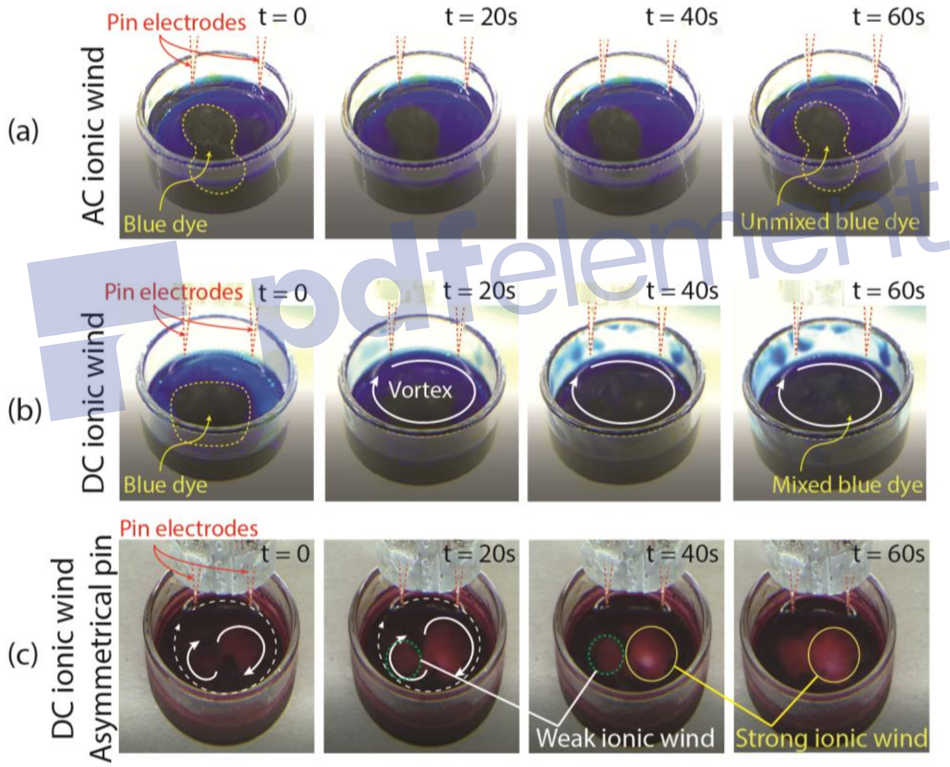


Figure 4. Experimental result of mixing processes.

Mixing application is also investigated using an air flow to mix dipropylene-glycol-monomethyl-ether and blue/violet dyes. No vortex on the liquid surface was created by the AC system in spite of the presence of ion winds observed by the liquid surface deformation (Figure 4a). As a result, dyes did not likely redistribute because of the flow jet symmetry. In other words, the jet is almost neutralized and hence does not carry charges to dyes. Meanwhile, a vortex whose shape varies with electrodes' geometry rotates in the clockwise direction by the DC ion wind system (Figure 4b). Dyes are then redistributed after a few seconds. For asymmetrical DC ion wind system, dyes are also redistributed and two blank regions are appeared just underneath the electrodes, while the fluid rotates in the clockwise direction (Figure 4c). The mixing process is fast and strong, possibly not only from winds themselves but also by the assistance of charged dyes. Devices based on the proposed configuration can be significantly miniaturized and potential for mixing applications.

CONCLUSION

A bipolar ion wind generator configured by parallel arranged electrodes in centrifugal mixing applications is investigated. The proposed configuration simultaneously generates negative and positive ion winds. The created ion winds are mixed and neutralized by together while travelling toward liquid surface. Experimental results confirm that the mixing of liquid occurs in different ways with the system generated by direct current (DC) or alternating current (AC). Furthermore, the mixing can be enhanced by electrodes of different tip diameters. The proposed ion wind generator is suitable for centrifugal mixing applications.

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