Particle Image Velocimetry Measurements of Wire-non-parallel Plate Induction Fan Type Electrohydrodynamic Gas Pump

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Abstract. 2D and 3D PIV measurements were performed in wire-non-parallel plates type EHD gas pump. The velocity distribution of generated flow was measured for various discharge conditions. The flow rates of generated flow were calculated by integrating 3D velocity profiles. The results showed that the present EHD gas pump is capable to generate fl flow rates of several hundred cm^3/s.

1. Introduction

When a strong electric field is generated between a sharp object at high voltage and a grounded electrode in a gas medium, a corona is formed resulting in ionization of the gas molecules. An organized ion flux in an electric field initiates an ion-driven wind of neutral molecules (electrohydrodynamically induced gas flow) is generated. When the electrodes configuration results in unsymmetrical electric field distribution, the unidirectional gas flow can be generated i.e. EHD gas pumping Several electrodes geometries have been proposed for EHD gas pumps, such as needle-to-mesh, needle-to-ring, wire-to-rod, wire-non-parallel plate etc. In this paper the particle image velocimetry (PIV) technique was used to measure the flow velocity generated by the wire-non-parallel plate type EHD gas pump. It was already demonstrated that the PIV is able to measure flow velocity fields in similar discharge conditions [1].

2. Experimental set-up

The EHD gas pump was made of transparent acrylic sheet of thickness of 1 cm. The internal dimensions 120x35x50 mm. Two engraved slits with 3° conversion angle were made in two sidewalls. Two plates supporting grounded electrodes could slide-in and off in the engraved slits. When the supporting electrodes were placed in the EHD gas pump body, the cross sections of pump exit and inlet were of 35x24 mm and 35x12 mm, respectively. The grounded electrodes (75x35 mm) were made off aluminum tape of thickness of 50 μm and placed onto the supporting plates in the desired position. The wire electrode was stainless-steel wire of diameter of 0.23 mm and width of 35 mm placed in between the plate electrodes. Changing the electrodes geometry (both, wire and grounded electrodes) affects the pump performance, even can change direction of generated flow [2]. In this paper the one position of corona wire electrode (21 mm from pump inlet) and one position of grounded electrodes (36 mm from pump inlet) are investigated. The EHD gas pump was placed

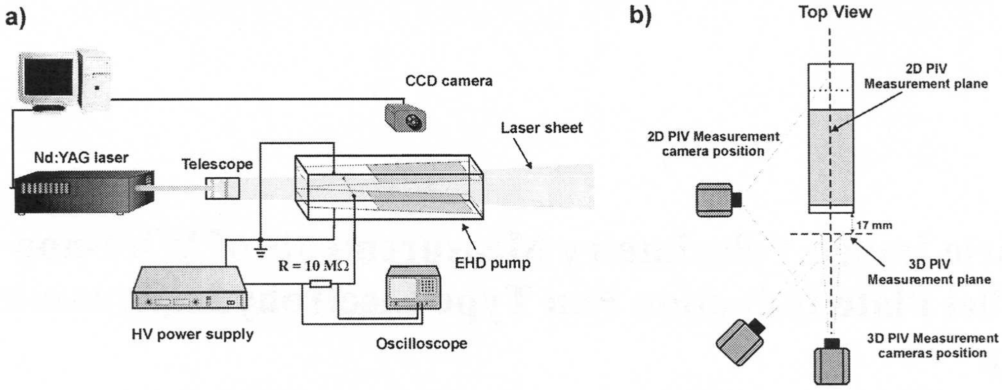

Figure 1 (a) Experimental set-up (b) measurement planes for 2D and 3D PIV measurements

between two acrylic boxes (11x14x40 cm). From the other end boxes were connected each other by the plastic tube (ϕ=6 cm) forming closed loop.

DC high voltage was applied to the wire electrode in EHD gas pump passing through protection resistor (10MΩ) by DC power supply (Spellman SL300.). Applied voltage was measured by high voltage probe (Tektronix, P6015A). Plate electrodes in EHD gas pump were grounded. The time average discharge time averaged corona current was measure by means of voltage drop on 10MΩ resistor. Both, the voltage and the time averaged corona current waveforms were recorded by digital oscilloscope (Tektronix, TDS3052B).

The PIV measurements were carried out using the PIV equipment similar to previous work [1] and consisted of a twin second harmonic Nd-YAG laser system (λ=532 nm, pulse energy 50 mJ), imaging optics, two CCD cameras, image processor (Dantec PIV 2000), and PC computer (figure 1a). The laser sheet, which defines the measuring plane, of a thickness of 1 mm, formed from the Nd-YAG laser beam by a cylindrical telescope, was introduced into the EHD gas pump. Cigarette smoke particles (0.5-1μm diameter) were used as a seed tracers [1]. The particle images were recorded by the FlowSense M2 CCD camera which was able to capture two images with minimum time separation of 2 ms. The CCD camera active element size was 1600x1186. The captured images were transmitted by the Dantec PIV 2000 image processor to the PC computer for digital analysis.

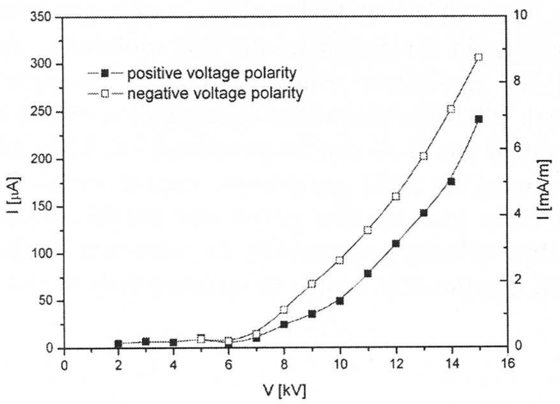

Figure 2. Time averaged corona current - voltage characteristics of EHD gas pump.

3. Results

The time averaged corona current - voltage characteristics are shown in figure 2, for the both, negative and positive polarities. 2D PIV measurement was performed in the plane perpendicular to wire electrode in the center of EHD gas pump (z=0) (figure 1b). The corona onset appears for 6 kV of applied voltage. For discharge voltages of 6-8 kV, the EHD recirculation flow structures appeared near corona wire, however no significant unidirectional flow can be observed. The overall unidirectional flow toward pump exit occurs for discharge voltage higher than 8-9 kV. When overall unidirectional flow established, vortexes formed inside pump are lost and gas flow generated by EHD force becomes homogenous. In figure 3 the velocity vector maps and corresponding streamlines of flow generated in EHD gas pump for negative and positive voltage polarity of 15 kV are shown.

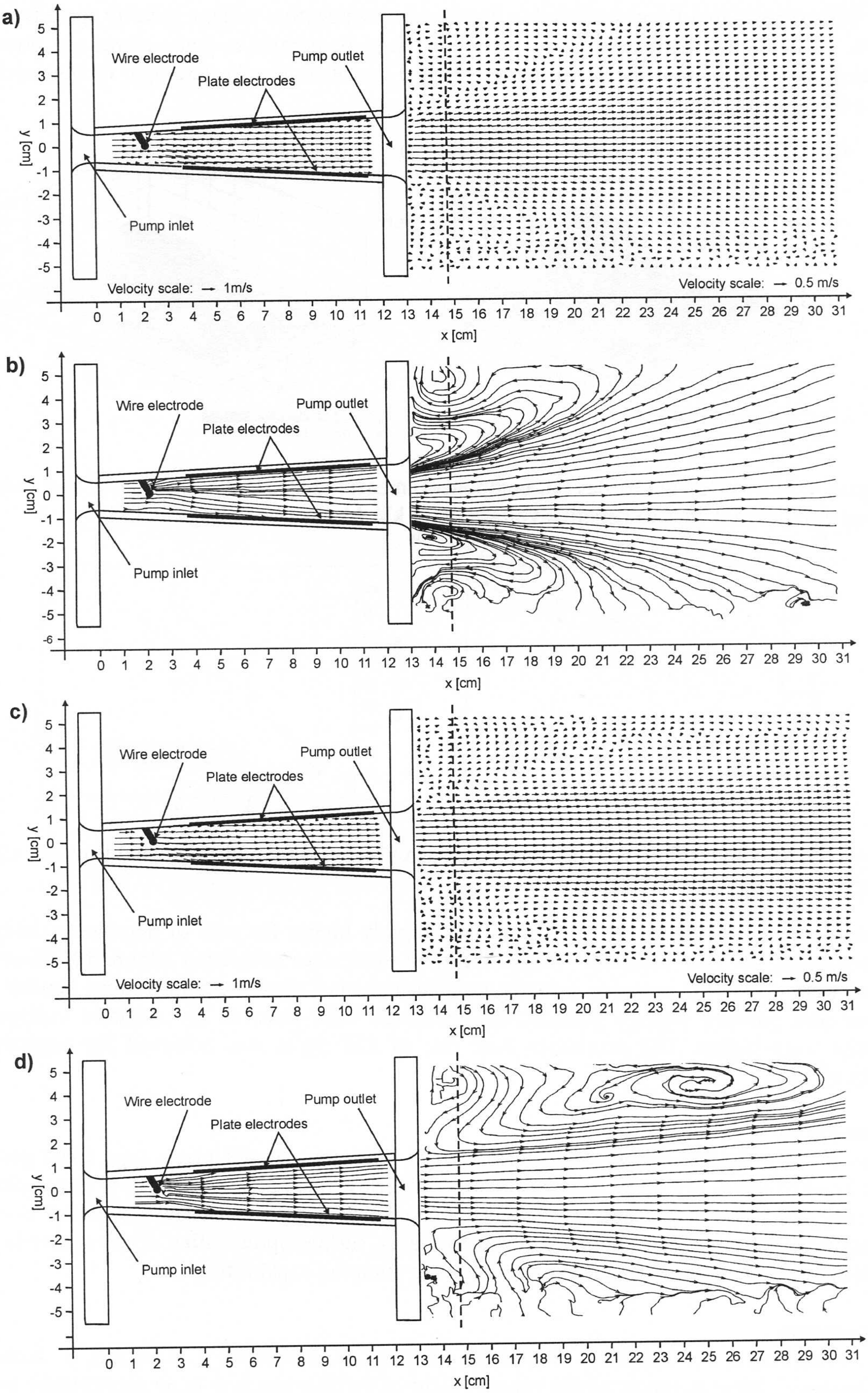

Figure 3. Flow velocity vector maps (a, c) and flow streamlines (b, d) for negative (a,b) and positive (c,d) discharge voltage polarity. V=±15 kV, z=0 (along the centre axis of the EHD gas pump).

Figure 3 also shows that flow generated in discharge with negative voltage polarity spreads wider than positive. 3D PIV measurements were performed in the plane parallel to pump plane, and flow rate was determined at 17 mm from the pump outlet (dashed line in figure 3). Example of obtained velocity profiles are shown in figure 4.

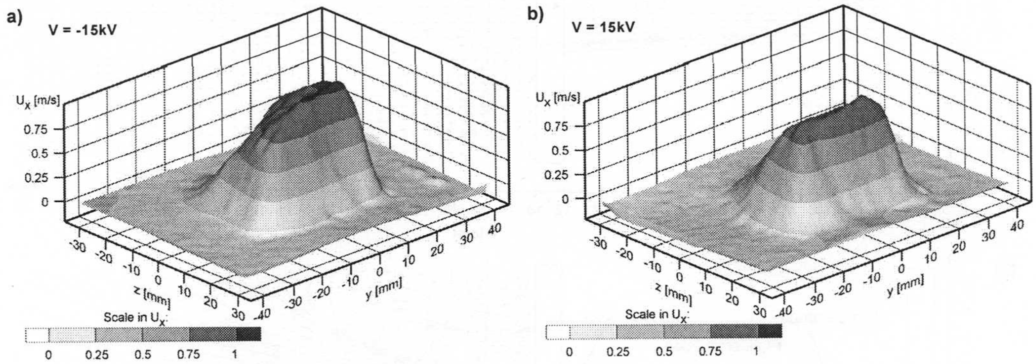

Figure 4. Flow velocity profiles (U_x component) measured by 3D PIV method 17 mm from pump exit (x=14.7 cm). a) negative voltage of 15 kV, b) positive voltage of 15 kV.

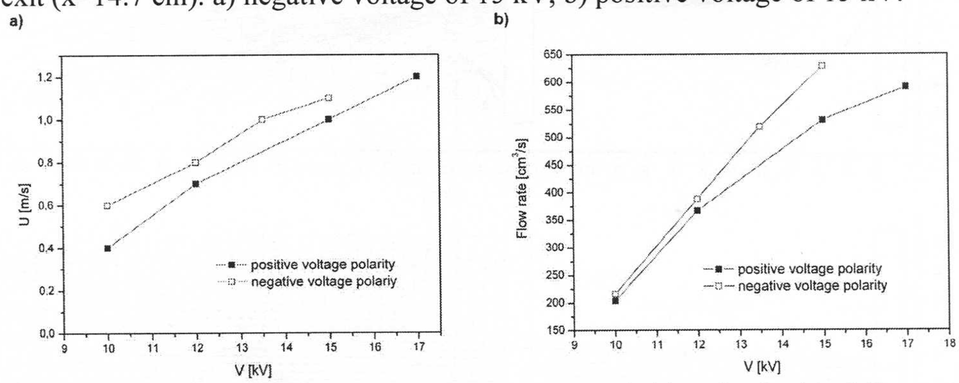

Figure 5. Maximum flow velocity (measured at x=14.7 cm) (a) and calculated flow rates (b) for negative and positive voltage.

The maximum flow velocity at x=14.7mm was slightly higher for case of negative polarity (Figure 5a). Integrating the flow velocity profiles the flow rates were calculated (figure5b). Since the flow profiles were wider for negative polarity voltage and max. flow velocities were similar for both, negative and positive voltage polarity, the measured flow rates in for negative voltage polarity discharge were higher. The maximum flow rate of 628 cm^3/s was achieved for negative voltage polarity of 15 kV.

4. Conclusion

2D and 3D PIV measurements were performed in wire-non-parallel plates type EHD gas pump at positive and negative discharge voltage polarity. The flow rates of generated flow were calculated by integrating 3D velocity profiles. The results showed that the present EHD gas pump is capable to generate flow rates of several hundred cm^3/s. However, further optimization of the electrode geometry and discharge parameters is required to improve the pumping capabilities.

References

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