Flow velocity field in flow stabilized hollow needle–to–plate electrical discharge in atmospheric pressure air

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The objective of this work was to study the flow velocity field in a reactor with a hollow needle–to–plate discharge stabilized by the air flow from the needle(s). The Particle Image Velocimetry (PIV) measurements showed that after reaching the plane electrode the fast air flow from the needle (average velocity of 200 m/s) spreads and flows with a velocity of up to 100 m/s in a narrow layer (up to 1 mm thick) along the plane electrode outwards. The bulk air mass in the reactor is not stagnant but circulates with a velocity of 1–5 m/s. The relatively fast air flow along the flat electrode is caused by the massive air outcome from the hollow needle(s) rather than by the electrohydrodynamic (EHD) effect, which is typical of the non–thermal plasma reactors without flow stabilization of the discharge.

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1 Introduction

Several types of the non–thermal plasma reactors with various kinds of the electrical discharges (dielectric barrier discharge, DC and pulsed corona discharge, DC atmospheric pressure discharge stabilized by a fast gas flow) have been proposed for the abatement of gaseous pollutants (e.g. [1, 2]). Recently, a new version of the DC atmospheric pressure discharge, a so–called atmospheric pressure hollow needle–to–plate (HN–to–P) electrical discharge has been proposed [3, 4] for gaseous pollutant destruction. In the HN–to–P reactor the discharge is stabilized similarly as in the atmospheric pressure flow stabilized corona [5] and corona radical shower discharge [6], i.e. by a gas flow through the hollow needle(s). However, in the HN–to–P discharge the gas flow velocity through the needle (about 150 m/s) and averaged discharge current (about 1 mA per needle) are higher than those in [5] and [6], while the interelectrode gap (several millimetres) is shorter.

The HN–to–P discharge was tested in the decomposition of hydrocarbons (HC), proving its potential for gaseous pollutant abatement [4]. The test showed that the HC decomposition efficiency strongly depends on the residence time of the operating gas in the reactor. However, the residence time is dependent on many factors associated with a complicated gas flow pattern in the HN–to–P discharge reactor, resulted from the gas expansion from narrow needle(s), back reflection of the gas stream from the counterelectrode, mixing of the flows if many needles are used, etc.

To elucidate the flow effects in the HN–to–P discharge we measured the flow velocity fields in a reactor with one or three hollow needles, using Particle Image Velocimetry (PIV) method. The results are presented in this paper.

2 Experimental set–up

The experimental set–up, consisted of a reactor, power and gas supply units, and PIV measuring system is shown in Fig. 1. The reactor, similar to that presented in [3] and [4], was a rectangular acrylic box of a height of 10 cm or 2 cm, width – 20 cm and length – 50 cm. In the middle of the reactor one or three stainless steel hollow needles (of an outer diameter of 1.8 mm and inner diameter of 1.2 mm) were placed as the stressed electrode(s). The tip of each hollow needle was sharpened at an angle of 15°, forming an elliptic outlet. The needles were placed perpendicularly to a stainless steel plate, which was used as the grounded electrode. The distance between each hollow needle tip and the plate was 3.9 mm. When 3 needles were used the distance between them was 8 mm and the elliptic outlets of all needles were oriented in the same direction. The experiment was carried out with dry air which flowed through the needles with a flow rate of 13 l/min per needle. No other forced flow was applied.

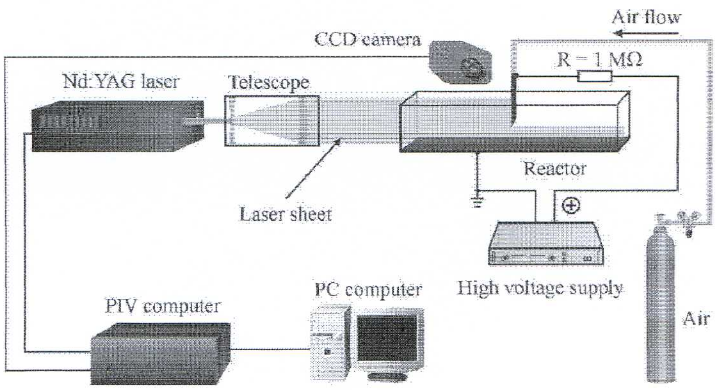

Fig. 1. Experimental set–up.

Each hollow needle was supplied separately from a dc source through a resistor of 1 MΩ resistanceu The needles were polarised positively. The time–averaged discharge current was 1 mA per needle at the applied voltage of about 7 kV.

PIV method is based on observation of the laser light scattered by the seeding particles following the flow. In this experiment cigarette smoke was used as seeding. It was added either to the air flowing through the hollow needle(s) or to the air present in the reactor. The PIV measurements of the flow velocity field in the reactor were carried out with a standard PIV equipment (Dantec PIV 1100) consisting of