

# Bubble Flow Measurements in Pulsed Streamer Discharge in Water Using Particle Image Velocimetry

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**Abstract.** In this paper the flow velocity fields during formation and motion of gas bubbles produced by a high voltage pulsed streamer discharge in water are presented. The discharge reactor was a glass parallelepiped filled with distilled water. In the water one or three stainless steel needles and a brass cylinder were placed. The Particle Image Velocimetry (PIV) measurements of the bubble flow pattern were carried out in six different planes, crossing the reactor. We observed that the bubble flow from the needle tips toward the cylindrical electrode was relatively strong and vortices were formed. Owing to it the water was stirred in the whole reactor volume, and the whole reactor volume was filled with bubbles.

## 1. Introduction

An application of high voltage pulsed discharge for water purification from organic compounds has been investigated for many years. The concept of such studies is to use several features of pulsed discharge in water. One of them is generation of chemically active species such as OH, H, O, H<sub>2</sub>O<sub>2</sub> and O<sub>3</sub> [1-4]. Their production is determined by several parameters such as applied peak voltage, polarity, rise time, electrode tip curvature radius and water solution properties (composition, pH and conductivity). All these parameters determine formation of plasma channel in water during the pulsed discharge. This channel emits ultraviolet radiation and its expansion through the surrounding water generates shock waves and gas bubbles. The bubbles are filled with the gas, which can contain the gaseous hydrogen, water vapour and oxygen. The size and the velocity of the bubbles, and also rebounds of the bubbles as a function of hydrostatic pressure, electrical energy and nature of the liquid have been measured in a few laboratories [5-7].

In this paper the flow velocity fields during formation and motion of the gas bubbles produced by the high voltage pulsed discharge in distilled water in reactor with one or three discharge needles are presented. The measurements were carried out using Particle Image Velocity (PIV) method [8].

## 2. Experimental apparatus

The experimental setup consisted of a reactor, DC power supply with a rotating spark gap switch and PIV equipment for a measurement of the flow velocity fields (Fig. 1).

The reactor was a glass parallelepiped (35 mm wide, 150 mm long and 120 mm high) filled with distilled water. The reactor was equipped with three stainless steel needles and a brass cylinder. The distance between the needles was 50 mm whereas the needles-cylinder spacing was 55 mm. The measurements were carried out with one or three needles grounded. The pulsed positive discharge was generated between a grounded needle electrode(s) and a high voltage negatively polarized cylinder.

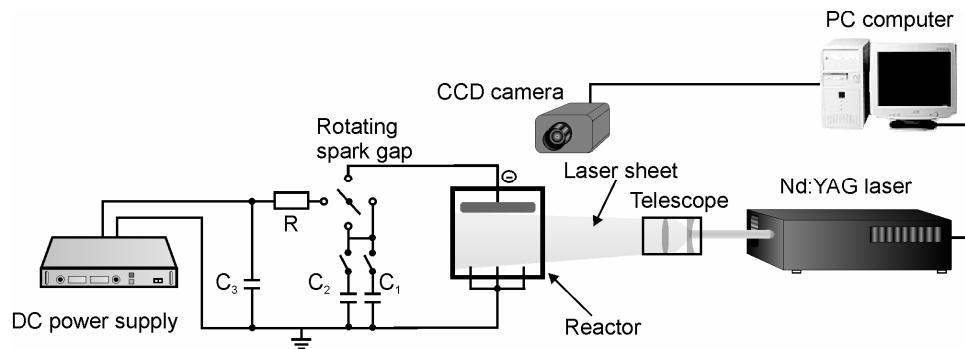


Figure 1. The experimental apparatus.

The positive high voltage pulses of 25 kV were applied to the needle electrode(s) from discharge capacitors:  $C_1$  (0.7 nF),  $C_2$  (2 nF) or both (2.7 nF). The capacitors were charged from a DC power supply through a resistor  $R$  (10 k $\Omega$ ) and a capacitor  $C_3$  (22 nF). The current pulses were up to 0.5 A with FWHM (Full Width Half Maximum) up to 80  $\mu$ s. Pulse repetition rate of 50 Hz was determined by the angular velocity of the rotating element in the spark gap switch.

The two dimensional (2D) PIV equipment consisted of a double Nd:YAG laser with pulse energy of 50 mJ, optics for transmission and formation laser beam, CCD camera and PC computer with FlowManager software. The bubbles produced during the discharge were used as a seed.

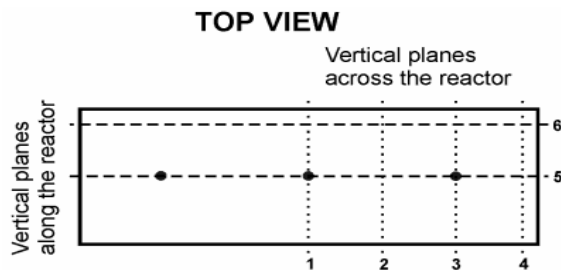


Figure 2. The observation planes in the reactor.

The PIV measurements were carried out in six vertical measurement planes (Fig. 2) in the reactor with one or three needles connected to a one or two capacitors. Due to the limited size of this paper only selected results are presented.

All the velocity fields presented in this paper resulted from the averaging of 190 measurements, which means that each velocity map was time-averaged.

### 3. Results

Figs. 3 and 4 show the bubbles flow patterns in the plane 5 (see Fig. 2) along the reactor with single needle electrode for capacitance of 0.7 nF and 2 nF, respectively. It is seen that the bubble flow from the needle tip toward the cylindrical electrode was relatively strong. Bubble vortices were formed under the cylindrical electrode on both sides of the discharge region. They transported the bubbles back toward the discharge region. Owing to it the water was stirred in the whole reactor volume and the whole reactor was filled with bubbles.

Bubble velocity depends on the capacitor used in the electrical circuit. In the discharge region it was up to 28.9 mm/s and 54.0 mm/s, respectively, when capacitors  $C_1$  (0.7 nF) and  $C_2$  (2.0 nF) were used. Aside the discharge region, where bubbles flowed downward, their lowest velocities measured in experiments with capacitors  $C_1$  and  $C_2$  were 2.8 mm/s and 4.0 mm/s, respectively.

The bubble flow patterns in the reactor with 3-needle electrode measured in the plane 5 (see Fig. 2) are presented in Figs. 5 and 6. It can be seen that three bubble flow streams corresponding to each discharge region were formed. On both sides of each discharge region vortices were formed. They transport bubbles downward in direction of needles. In both cases, for capacitances of 2 nF (Fig. 5) and 2.7 nF (Fig. 6), the bubbles flow looks similarly, and the flow velocities are similar: maximum velocity in the needle-cylinder direction was 38.0 mm/s in Fig. 5 and 35.6 mm/s in Fig. 6 and minimum velocity in the cylinder-needle direction was 10.0 mm/s in Fig. 5 and 9.2 mm/s in Fig. 6. Only over the left needle when 2 nF capacitor was used we could observe lower velocity what indicates weaker discharge generated at this needle comparing to the others.

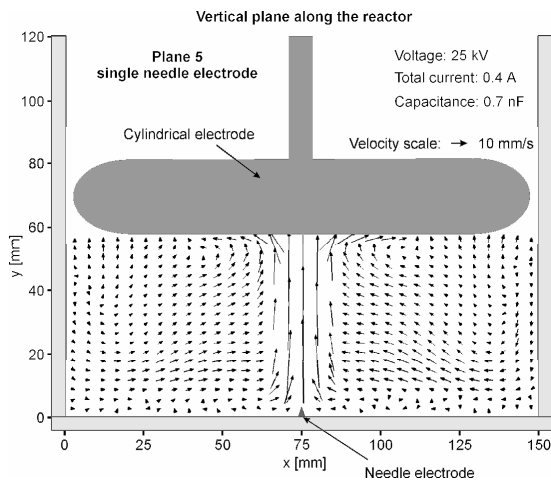


Figure 3. Flow velocity field in the plane 5 along the reactor with single needle electrode. The discharge capacitor 0.7 nF.

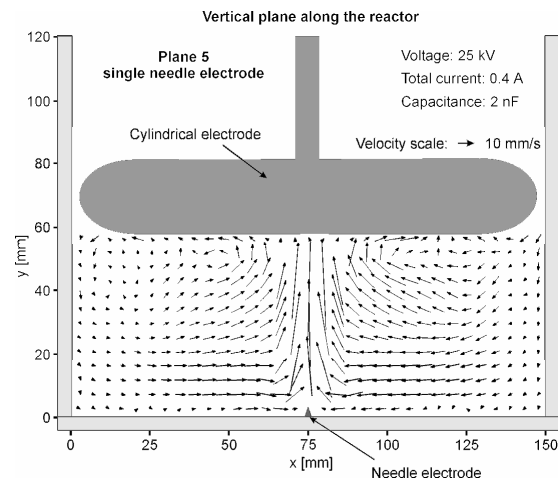


Figure 4. Flow velocity field in the plane 5 along the reactor with single needle electrode. The discharge capacitor 2 nF.

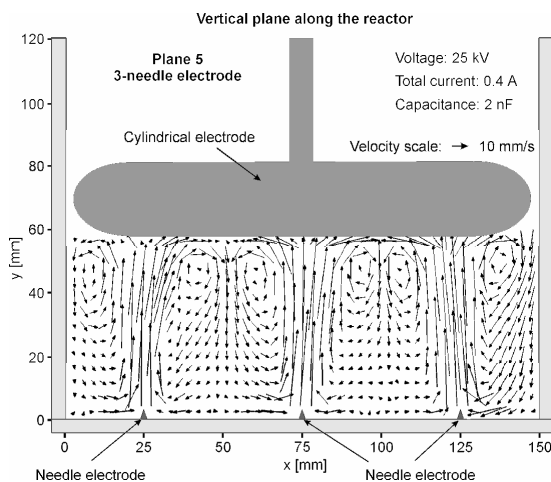


Figure 5. Flow velocity field in the plane 5 along the reactor with three needle electrode. The discharge capacitor 2 nF.

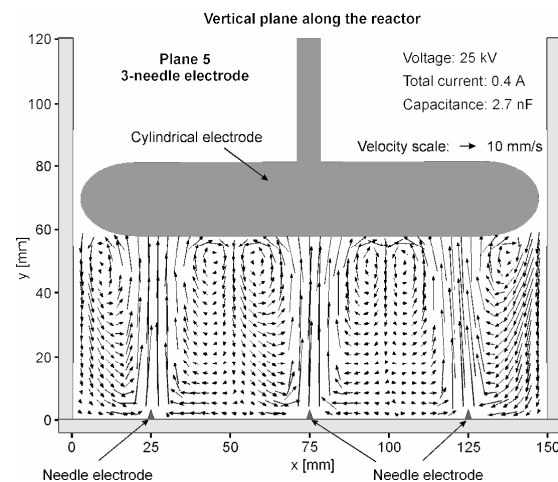


Figure 6. Flow velocity field in the plane 5 along the reactor with three needle electrode. The discharge capacitor 2.7 nF.

In the plane 6 (see Fig. 2) passing along the reactor but behind the needles, motion of the bubbles was generally similar to that observed in the plane 5. The bubbles first flowed from the needle tip vicinity toward the cylindrical electrode and then turned back, to the discharge region, forming vortices. There was also an influence of the supplying capacitor on the size of vortices and velocities. Due to the limited size of this paper the results measured in the plane 6 are not showed.

The movement of the bubbles was measured in 4 vertical planes across the reactor (see Fig. 2). It was found that in the reactor with single needle electrode bubble flow velocities in all planes increased with capacity of the supplying capacitor. In the plane passing through the middle needle (plane 1 in Fig. 2) the bubbles moved in the relatively wide stream upward. When capacitor of 2.0 nF was used, the velocity was up to 61.4 mm/s (Fig. 7a). In the plane 2 bubbles were still transported toward the cylindrical electrode, however with much lower velocity, and they circulated in vortices formed close to cylindrical electrode (not showed in this paper). In planes 3 and 4 the flow of the bubbles was directed downward. In the plane 3 vortices were formed (not shown in this paper). Velocity of bubbles in the plane 4 was up to 12.3 mm/s at 2.0 nF capacitor (Fig. 7b).

In the vertical planes 1 and 3 passing over needles across the reactor with 3-needle electrode the flow of the bubbles was directed toward the cylindrical electrode and was accompanied with formation of vortices. The downward flow of the bubbles with small swirls was observed in planes 2 (between the needles) and 4 (6 mm from the reactor side wall). The results measured in the planes across the reactor with 3-needle electrode are not showed in this paper.

#### 4. Conclusions

The experiment was focused on the PIV measurement of the bubbles flow during the pulsed discharge in the reactor with single needle electrode and 3-needle electrode, filled with distilled water with different supplying capacitors. We observed that the bubble flow from the needle tip towards the cylindrical electrode is the strongest stream. Under the cylindrical electrode vortices appear, which transport scattered bubbles back towards the discharge region(s) and they cause mixing the water in the whole reactor volume. During the discharge the whole reactor volume is filled with the bubbles.

We found that flow velocities in the reactor with single needle electrode increased with capacitance of supplying capacitor. Supplying capacitor influenced also the size of vortices and the plane of their formation. Increase in the capacitance of that capacitor resulted in growing the vortices and shifting their centers from the vicinity of the sidewalls toward the discharge region.

In the reactor with 3-needle electrode there was insignificant influence of supplying capacitor on the bubbles flow patterns and velocity. However, it must be noticed that the range of examined capacitance was relatively low, i.e. 2.0-2.7 nF.

Results of PIV measurements showed that flow in our reactors of pulsed positive streamer discharge in water ensure good mixing and does not require additional mechanical stirrer.

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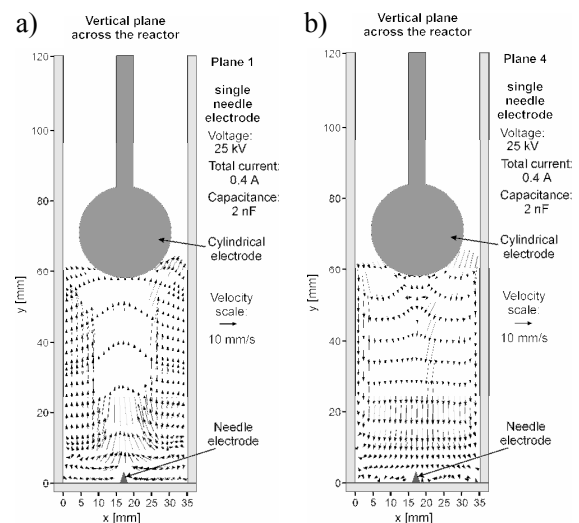


Figure 7. Flow velocity field in the plane 1 (a) and plane 4 (b) across the reactor with single needle electrode. The discharge capacitor 2 nF.