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Streamers Induced by Dielectric Barrier Electrohydraulic Discharge

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Streamers in water plasma induced by a dielectric barrier hydraulic discharge are observed with a high-sensitivity digital camera. The barrier-type plasma reactor consists of a stainless-steel needle high-voltage (+35－+65 kV) electrode partially immersed in a solution and a glass solution container wrapped with an aluminum film as the grounded electrode. Many filamentous discharges or streamers are clearly observed in water under a high voltage of 50 kV. Efficient dissociation of hydrogen peroxide generated by the plasma under alkaline conditions is a key for water treatment or dye decolorization with radicals' generation.

1. Introduction

Recently, generating a plasma stably in water or an electrohydraulic discharge plasma using pulsed power technology with an extremely high voltage in a very short time (of the order of a nanosecond) has become possible. Therefore, studies on applications such as solution treatment, sterilization, and decolorization have received considerable interest[1, 2]. However, when a pulsed high voltage is applied between the electrodes, as the voltage is increased the streamer discharge (which has higher energy efficiency for the treatment) can easily transit to a spark discharge. Such a spark discharge requires high electrical energy and exhibits lower energy efficiency for the treatment. Therefore, maintaining a streamer discharge is preferable. To do it, the dielectric barrier between electrodes is effective as is the case with gas electrical discharge. In this study, following the previous one[3], characteristics of streamers induced by a dielectric barrier electrohydraulic discharge are investigated.

2. Experimental apparatus and methods

A schematic diagram of the experimental setup is shown in Fig. 1. A Pyrex glass beaker (with an inner diameter of 6.24 cm, a glass thickness of 1.8 mm, and a liquid volume of 200 mL) is filled with pure distilled water or a dye solution. A stainless-steel needle electrode (with a diameter of 1 mm) is completely covered in a polytetrafluoroethylene (PTFE) tube, except for the tip, which is immersed in water to a depth of 3 cm and used as a positive electrode. Aluminum foil tape is wrapped around the outside and bottom surfaces of the beaker as a grounded electrode. A high-voltage pulse is applied between the electrodes using a pulsed power source (with a gap of 4–6 mm) (Masuda Research Inc., Japan). The applied output voltage is 10–65 kV, the pulse width is 540 ns, and the pulse frequency is 120 pulses per second (Hz). The circuit consists of a protection resistance (3 MΩ), a load resistance (50 kΩ), a capacitor (1 nF), and an inductor (4.7 mH).

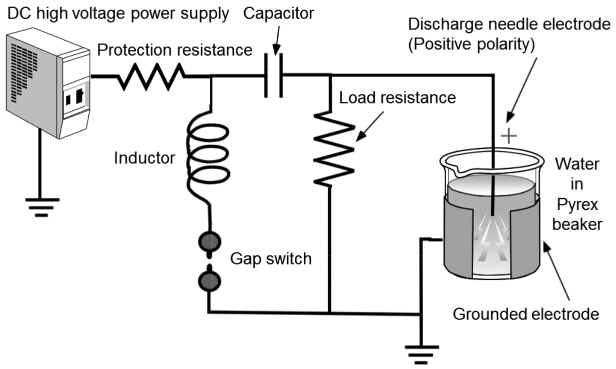

Fig.1 Experimental setup.

3. Experimental results and discussion

When the applied voltage is 50 kV, a series of electrohydraulic discharge streamers that start from the tip of the needle electrode are observed, as shown in Fig. 2. A higher voltage more than 50 kV can be maintained by the dielectric plasma reactor. As a result, high power density can be realized. The photographs in Fig. 2(a)–(c) are taken in distilled water with different digital camera (Nikon Coolpix 5000) exposure times. For example, streamers during (1/15)/(1/120) = 8 periods of the high-voltage pulse are captured in Fig. 2(c). In the figures, a significant number of small bubbles can be seen to be released from the streamers. The composition of these bubbles is investigated using a gas detection tube (Gastec Corp.). As a result, ozone (~60 ppm) and hydrogen (~0.1％) were detected near the water surface. Furthermore, free radicals such as

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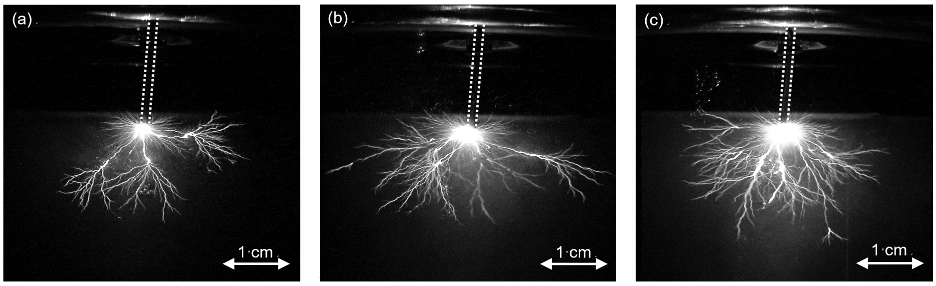

Fig.2 Structures of streamers. Digital-camera exposure times are (a) 1/60 s, (b) 1/30 s, and (c) 1/15 s. The locations of the needle electrode covered by the PTFE tube are indicated with dotted lines.

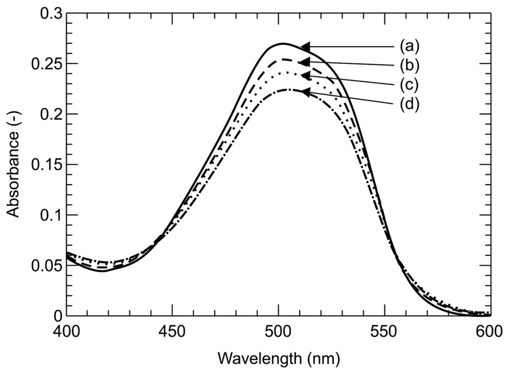

Fig.3 Optical absorbances in the dye decolorization: (a) untreated; treatment times of (b) 10 min, (c) 20 min, and (d) 30 min.

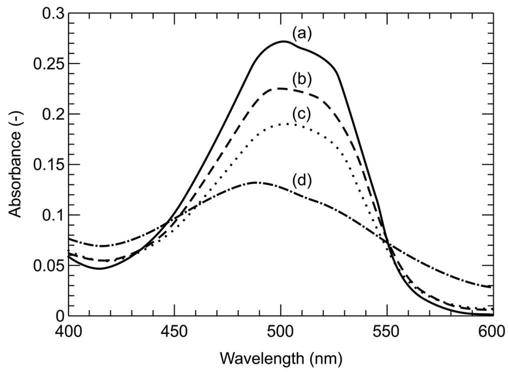

Fig.4 Optical absorbances in the dye decolorization: (a) untreated, (b) immediately after 30-min plasma application, (c) 1 day after it, and (d) 1 day after it with the addition of Na_2CO_3.

hydroxyl and hydrogen radicals were successfully detected in the solution using electron spin resonance measurements[3].

Fig. 3 shows time-dependent changes in the optical absorption of the dye (Reactive RED 106) solution with a concentration of 0.01 g/L after plasma application for 0–30 min. Under conditions of a dye solution concentration of 0.01 g/L (electrical conductivity = 79 μS/cm) and an applied voltage of 65 kV (with a pulse width of 540 ns and a pulse frequency of 120 Hz), a series of streamer discharges is observed. A discharge energy of a single pulse is approximately 0.46 J. The graph in Fig. 3 shows that decolorization advances and optical absorption decreases with the increase in the plasma treatment time. However, the decolorization or decrease is not very large. Next, after treating the dye solution, the alkali chemical Na_2CO_3 is added. The result on the optical absorption is shown in Fig. 4. In the case (b), after 30-min plasma application, the absorbance is measured immediately. In the case (c), the solution is left in the laboratory for a day after it. In the case (d), the solution is left there for a day after it with the addition of Na_2CO_3. The result shows that the absorption at a wavelength of about 500 nm disappears and that the color of the solution becomes faint. The mechanism of decolorization has been clarified in a previous paper[3]. The dissociation of hydrogen peroxide (H_2O_2) advances under alkaline (Na_2CO_3) conditions[4], and the superoxide anion ($\bullet O_2$) and perhydroxyl radical ($\bullet OOH$), as well as hydroxyl radicals ($\bullet OH$), are induced. They are very effective for decolorization.

4. Conclusion

The structures and treatment performance of streamers in a water plasma induced by a dielectric barrier hydraulic discharge are investigated. A higher voltage can be maintained by the dielectric plasma reactor. Efficient dissociation of H_2O_2 generated by the plasma under alkaline conditions is a key for water treatment with radicals' generation.

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