Properties of ball-lightning discharge for waste water processings

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Abstract

The electrode configuration by Egorov, et.al.[1] can produce a ball-lightning discharge with a diameter larger than 10 cm and a duration of 100 ms, in addition to an upward intensive water jet and bright spectrum originating from OH radicals[2]. In this study, we investigated the relevant condition of the electrode geometries(diameter of rod electrode and shape of electrode underwater) and demonstrated its parallel operation for the practical application to the water treatment systems.

Introduction

The water decomposition procedures of persistent chemicals such as dyes, et.al.[3], using electric discharge methods are studied actively. However, because of the higher breakdown voltage in water and narrow reaction area of a streamer or arch configuration, another discharge process with a wider reaction area is required for a large-scale processing.

A ball-lightning or fireball discharge larger than 10 cm in diameter and with a time duration greater than 100 ms can be generated using specific electrode configurations[4-6]. Furthermore, Maeyama and Tanaka[2] reported the existence of an intensive upward water jet into the reaction field at the beginning of the discharge, a strong radiation spectrum originating from OH radicals, and the potential for the water processing applications.

In this study, we examined the relationship of the geometric parameters and the configuration of the electrodes and the discharge properties. We also demonstrated parallel operation with three electrodes using the electric current path in the water as a ballast resistance.

Experimental setup

The experimental setup is shown in Figure 1. The 183 μF capacitor bank can be charged up to $\pm$6 kV, and is connected in series to a switch of thyristors, 100 Ω resistance and two underwater discharge electrodes of the central rod electrode and the ring electrode. A resistance of 7 kΩ is connected between electrodes in parallel to set those electric

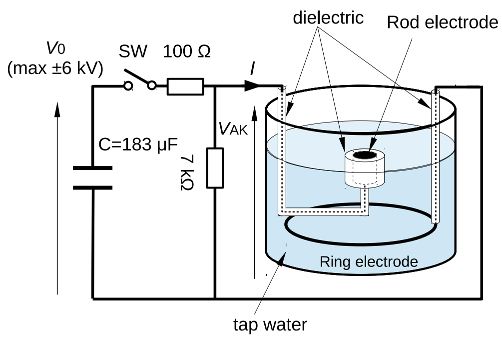


Figure 1: *Experimental setup*

potentials before the breakdown. Both electrodes are made from copper and underwater interconnected wires of 2 mm in diameter under water are covered with polyethylene tubes.

Figure 2 shows schematic diagrams of the rod electrode (a) without and (b) with an opening between the copper electrode and dielectric,where D is the diameter of the copper electrode. Figure 3 shows an assembly with three electrodes electrically connected in parallel, where each copper electrode of 8 mm in diameter and 1.6 mm in thickness is mounted on the dielectric plate.

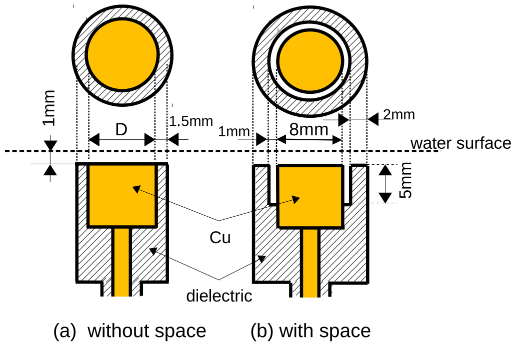


Figure 2: *The rod electrode configurations*

Experimental results

Using the rod electrode shown in Figure 2(a), the effects of its diameter D on the discharge volume were examined, where $|V_0| = 5.5$ kV, and the distance between the top of the rod electrode and the ring-electrode was set to 40 mm in tap water. Figure 4 shows flames of the discharge in the case of D = 8 mm and 10 mm and a negative polarity ($V_0 = -5.5$ kV). In particular, in the case of D = 10 mm, the discharge area expands over the entire container at t = 90 ms. Figure 5 shows the discharge diameter as a function of D at a time when the discharge rises above 4 cm from the water surface for (a) negative and (b) positive polarity. Additionally, in the negative polarity, the volume can be expanded using a rod electrode with a larger diameter. There is, however, a tendency for the discharge to be inhomogeneous in the case of small diameter of D = 4 or 6 mm. Figure 6 shows flames in the case of positive polarity and D = 10 mm. In this case, the discharge expands not radially but upward, and the diameter has no effect on the discharge volume from Figure 5(b).

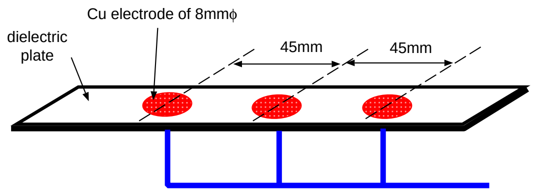
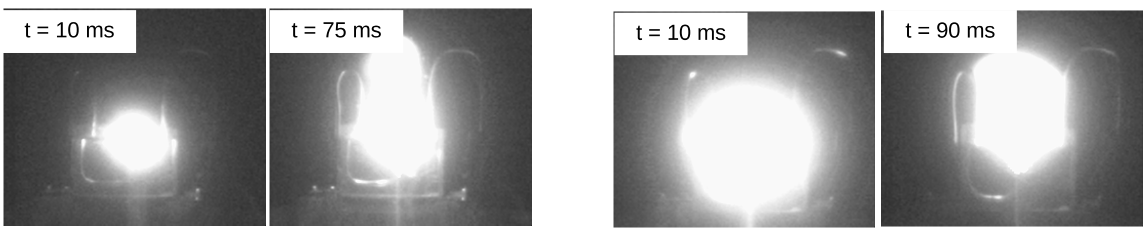


Figure 3: *Assembly of three parallel electrodes*

In the previous ball-lightning studies[6], a rod electrode with an opening or gap between a



(a) D = 8 mm (b) D = 10 mm

Figure 4: *Flames of the discharge in the negative polarity case*

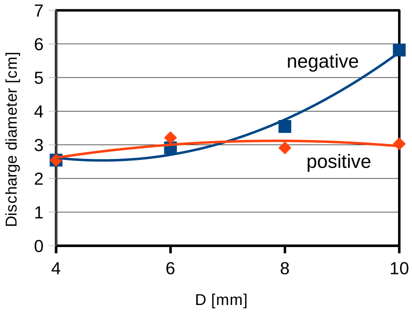


Figure 5: *The relationship of the discharge diameter and D*

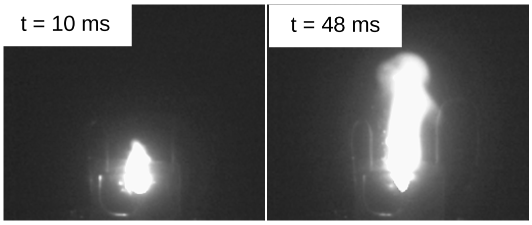


Figure 6: *Discharge flames in the case of positive polarity*

conducting material and a dielectric has been used. Consequently, we examined the gap effect of the electrode on the discharge using those without and with a gap ,but with the same copper diameter D = 8mm. In the results, we cannot recognize any difference in the discharge configuration, break-down voltage with or without the gap in both cases of polarities. Furthermore, the geometry of the bottom electrode , such as a (a) ring, (b) thin plate disk or (c) wire netting disk, also does not affect on the discharge, if there is a sufficient clearance with another electrode or wiring of approximately 4 cm in the case of $|V_0|$ = 4 $\sim$ 5 kV to avoid a direct arch discharge underwater.

The parallel discharge operations may be effective in increasing the water processing capability. By using a simple electrode assembly with three small thin disk electrodes on the plate, it was demonstrated that electric resistances along the current paths in the water may work as ballast resistances, and discharges can be generated in parallel. Figure 7 shows flames of this experiment in the cases of both polarities and tap water. For a ring electrode with a depth above 4 cm from the surface, three parallel fireball discharges were demonstrated.

(a) negative polarity (b) positive polarity

Figure 7: *Flames of parallel discharge operation*

Discussion and conclusions

Analysing a static electric field E (water relative permeability $\varepsilon_r = 80$) and flowing current density j (water conductivity $\sigma = 0.01$ S/m), the mechanism of the fireball discharge was discussed. Figure 8 shows a typical distribution of (a) $|E|$ and (b) $|j|$ in the case of $V_0 = 5.5$ kV and D = 10 mm. Because the maximum values of the electric field are 1.0 kV/mm on the surface

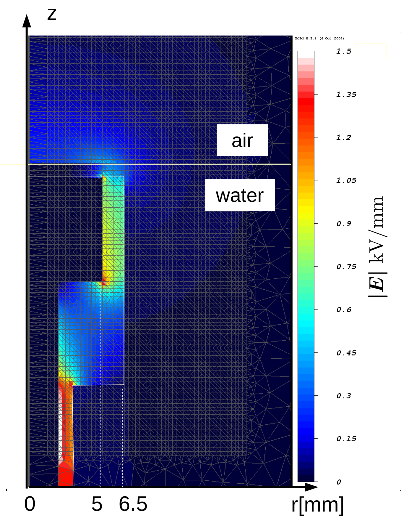


Figure 8: *Distribution of* $|E|$

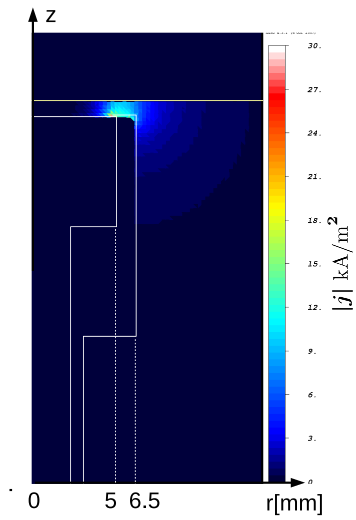


Figure 9: *Distribution of* $|j|$

and 2.5 kV/mm at the outer edge of the electrode in the water, the conventional gas or liquid breakdown mechanism does not apply to this discharge. From Figure 9 the current density j is concentrated along a narrow circumference of the electrode and reaches a maximum value of 16 kA/m^2. This leads to a significantly shorter time duration $\sim$ 10 μs, which is necessary for the annulus water ring above the electrode to vaporize (2.6 MJ/kg). Therefore the breakdown in air rich with water vapor may be the beginning of a fireball discharge[6].

In conclusion, radius of the rod electrode affects on the volume of fire-ball discharge especially in negative polarity case and the parallel operation using several rod electrodes can be demonstrated in both polarity cases.

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