Characteristics of gas phase discharge above water surface

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Abstract. Characteristics of gas phase discharge with both electrodes suspended above the water surface were investigated. Discharge channels propagated from electrode to electrode or from electrode to water surface were determined by the distance between electrodes, the distance from the high voltage electrode to water surface and the water conductivity. The voltage-current relation was almost not affected by water conductivity, the distance between electrodes and the distance from electrode to water surface unless spark occurred. However, the voltage-pulsed energy relation was affected by these factors. The larger water conductivity and smaller distance between electrodes and distance from electrode to water surface, the larger pulsed energy.

1. Introduction
A typical water surface discharge reactor suspended the high voltage (HV) electrode over the water surface and put the ground electrode in water [1, 2]. The discharge occurred in the air and on the air-water interface. Because of no directive contact between the HV electrode and the water, the leakage current was cut off by the air gap. The problem caused by large leakage current and joule heating could be alleviated in water surface discharge. So for high conductivity water treatment, water surface discharge was much more suitable. Numerous articles reported the discharge characteristics and applications of water surface discharge [3-8]. However, this arrangement of electrodes could not avoid the corrosion of the ground electrode by high conductivity water. A solution for this problem was suspending both the HV electrode and the ground electrode above the water surface. Depending on the distance between electrodes, the distance between the high voltage electrode and water surface, and the water conductivity, two kinds of discharge paths existed. Discharge channels from electrode to electrode or from electrode to water surface would afford different water treatment potentials. Therefore, transition criterions and electric characteristics of these two kinds of discharge channels must be considered before the utilization.

2. Experimental

2.1. Power supply
Schematic diagram of the main circuit of the power supply was shown in figure 1. The main components including a low-voltage rectifier (D1), a filter capacitor (C1), a DC/AC inverter (IGBT1-4, L1 and C2), a primary transformer (T1), a high-voltage rectifier (D2), energy storage capacitors (C), a pulse transformer (T2) and a hydrogen thyratron switch (Th). This system could output electrical pulses with peak voltage from 0 to 70 kV, repetition frequency from 0 to 200 Hz.
2.2. Reactor
The discharge reactor composed of a pair of graphite needle electrodes with tips of about 0.2 mm and the water surface. The distance between electrodes (L), the distance between the high voltage electrode and water surface (d1) and the distance between the ground electrode and water surface (d2) were labelled in figure 2 and could be changed. The area of the water surface was a constant (with a length of 20 cm and a width of 10 cm).

![Figure 2. Arrangement of the discharge system.](image)

2.3. Analytical procedures
The waveforms of pulsed voltage and current applied to reactors were monitored with a digital oscilloscope (Tektronix DPO 3000, USA), a 1:1000 high voltage probe (Tektronix P6015A, USA) and a current probe (Tektronix TCP 0150, USA).

3. Results and discussion
3.1. Discharge channel transition criterion
For spark discharge, along with the increase of electrode distance, discharge channels existed along L transitioned to along d1 and d2. Transition criterions were shown in figure 3 (a) as curves, above which spark channels propagated along d1 and d2, but below which spark channels propagated along L. The transition criterion curve moved downward when increasing the water conductivity.

For streamer discharge, discharge channels propagated along d1 and d2 existed invariably when decreasing the electrode distance. However, if the electrode distance was large enough, streamer channels along L disappeared. Curves in figure 3 (b) indicated the streamer channel transition criterions above which streamer channels propagated only along d1 and d2, but below which streamer channels propagated along d1 and d2 and along L coexisted.

The electrode distance, the distance from the electrode to water surface and the water conductivity influenced the direction of discharge channel. Increase of water conductivity, increase of electrode distance, and decrease of the distance from the electrode to water surface would be beneficial to the
propagation of discharge channels from the electrode to the water surface. Contrarily, propagation of discharge channels from the HV electrode to the ground electrode was more likely. That is to say, influence of the water surface could be enhanced by increasing the electrode distance and the water conductivity, and decreasing the distances from the electrode to the water surface.

![Figure 3](image)

**Figure 3.** Discharge channel transition criterion (a) spark channel, (b) streamer channel.

### 3.2. Effect of electrode distance on electrical characteristics

Experiments were conducted at three different electrode distances (15 mm, 22.5 mm and 50 mm), other conditions were kept identical. These different electrode distances would result in different directions of discharge channel which could be seen from the transition criterions indicated in figure 3. For streamer discharge, channels along L and d were coexist for electrode distances of 15 mm and 22.5 mm but propagated only along d1 and d2 for the electrode distance of 50 mm. For spark discharge, channels propagated along L for 15 mm but along d1 and d2 for 22.5 mm and 50 mm.

![Figure 4](image)

**Figure 4.** Effect of electrode distance on electrical characteristics, (a) voltage-current, (b) voltage-pulsed energy. (d1+d2=24.5mm, water conductivity=20mS·cm⁻¹)

Peak current was not influenced by the electrode distance unless spark discharge occurred which was shown in figure 4 (a). The peak current of spark channels propagated along L was much larger than that along d1 and d2. If the spark channels propagated only along d1 and d2, the peak current was not affect by electrode distance. Effect of electrode distance on pulsed energy was similar to that on
peak current. But the pulsed energy decreased with electrode distance even though the spark channels propagated only along \( d_1 \) and \( d_2 \).

3.3. Effect of the electrode-water surface distance and water conductivity on electrical characteristics

Effect of the distance from electrode to water surface was shown in figure 5. Experiments were conducted at five different electrode-water surface distances as shown in figure 5 (a), other conditions were kept identical. Spark channels propagated along \( L \) and streamer channels coexisted along \( L \) and \( d \). Effect of electrode-water surface distance on peak current could be ignored as shown in figure 5 (a). But pulsed energy decreased with the increase of the distance between the electrode and the water surface. For spark channels propagated along \( d_1 \) and \( d_2 \), the result was the same as figure 5 indicated.

![Figure 5](image1)

Figure 5. Effect of electrode-water surface distance on electrical characteristics, (a) voltage-current, (b) voltage-pulsed energy. (\( L=15 \) mm, water conductivity=20 mS·cm\(^{-1}\))

![Figure 6](image2)

Figure 6. Effect of water conductivity on electrical characteristics, (a) voltage-current, (b) voltage-pulsed energy. (\( d_1+d_2=24.5 \) mm, \( L=55 \) mm)

The influences of water conductivity on electrical characteristics were shown in figure 6. Spark channels propagated along \( d_1 \) and \( d_2 \) but streamer channels coexisted along \( L \) and along \( d_1 \) and \( d_2 \). Influence of water conductivity on peak current was little. But the pulsed energy increased with water conductivity for high voltages. When discharge channels only existed between electrodes, the effect of
water conductivity was much smaller.

4. Conclusions
The existence of the water surface influenced the gas phase discharge. For gas phase discharge without water surface, discharge channels propagated only between the electrodes. However, the existence of water surface would attract the discharge channels to propagate from electrode to the water surface. Increase of water conductivity, increase of electrode distance, and decrease of the distance from the electrode to water surface were beneficial to the propagation of discharge channels from the electrode to the water surface. Influence of these factors on streamer current and pulsed energy was little. However, occurrence of spark discharge would amplify the influence of these factors on electrical characteristics.

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