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Underwater current distribution induced by spark discharge on a water surface

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ABSTRACT

Discharge current distributions generated underwater by spark discharges from the atmosphere to free water surfaces with conductivities in the range 0.07–10.0 S/m were investigated using a laboratory-scale electrode system consists of a discharge electrode and nine underwater grounding electrodes. Discharge emission on the water surface, which shows significant change with slight increase in conductivity, affects the current distribution in the water. The electric potential of the water surface also changes significantly with slight increase in conductivity. Results of numerical calculations of the underwater discharge current based on the water surface potential agree with the experimental results.

1. Introduction

Electric discharge phenomena in dielectric two-phase gas-liquid systems have been extensively investigated from a physical viewpoint for many years. From an electrohydrodynamics viewpoint, electrostatic effects in insulating liquids have been well recognized for the role of interfacial sheer stress [1], flow pattern transitions [2], instability in fluid motion [3], and non-dimensional numbers for electrified interfaces [4] through dielectric and conductive forces. On the other hand, from a chemical perspective, exposure of conductive liquids interfaces with gases (which act as liquid electrodes) to corona or glow discharge is being widely investigated for various applications. Examples include plasma generation for aqueous phenol decomposition [5] and NO_x treatment methods [6], and maintenance of wet polluted insulators on high-voltage transmission lines [7]. Most investigations of discharge on water surface have focused on understanding its mechanism and nature by employing various types of discharges and electrode configurations. Examples of such studies include investigations of discharge transitions [8], plasma characteristics in an air gap [9,10], and leader extension of a spark discharge on a water surface [11]. When considering atmospheric discharge processes above liquid interfaces, it is important to determine the behavior of the surface potential and the current in the liquid.

Recently, electrolyte-cathode discharge in the atmosphere with water as the medium or as an electrode is one of the promising plasmas for water treatment [12–16]. Besides that, in concerns of lightning stroke to wind turbine generator system on the ocean [17], prediction of the discharge current within a seawater region circumference will be desired for the consideration of safe defense. Water, which contains ions and other impurities (except for pure water), makes a good conductor as the impurities increased [18], and the discharge characteristics in water environment also change under the condition of varied conductivity [19]. Surprisingly, the behavior of underwater current generated by spark discharges from the atmosphere to a water surface is still largely unknown, unlike the extensive knowledge about underwater discharges [20–22]. It is thus important to understand the effect of water properties on electrical conduction phenomena. This work experimentally investigates the effect of water conductivity on the underwater current distribution generated by spark discharge from the atmosphere to a water surface.

In this work, an electrode system with a free air–water interface was constructed to investigate the current characteristics dependence on the water conductivity during spark discharge in air. Spark discharges over a water surface (SDWS) were generated in this system by a applying a standard lightning impulse voltage. The

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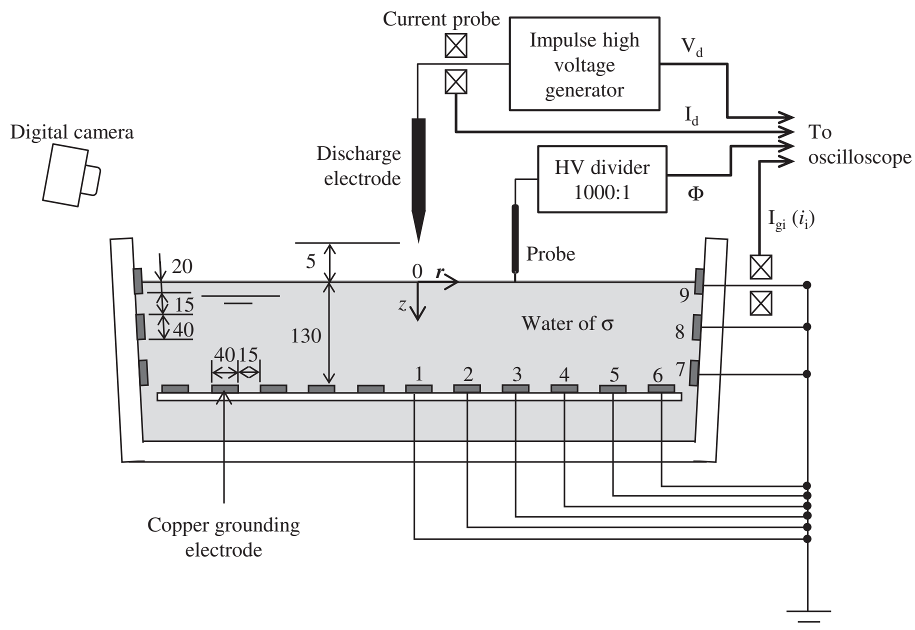

Fig. 1. Experimental setup; all dimensions are in mm.

temporal and spatial underwater current distributions were measured at nine grounding electrodes installed in a laboratory-scale water tub (depth: 130 mm; diameter: 750 mm). The potential of the water surface during spark discharge was measured and numerical analysis was performed based on the measured boundary conditions.

2. Experimental setup

Fig. 1 shows an axially symmetric electrode system whose grounding electrode consists of nine underwater electrodes, which are numbered from 1 to 9 radially. Electrodes 1–6 were aligned parallel to the water surface at a depth of 130 mm, while electrodes 7–9 were perpendicular to the water surface. Electrode 1 was a circular copper plate (thickness: 1 mm; diameter: 40 mm), while electrodes 2–6 were ring-shaped copper plates of the same thickness and their outer radius was 40 mm greater than their inner radius. Electrodes 7–9 were copper tape (thickness: 0.1 mm; width: 40 mm) attached to the inner surface of a 750-mm-diameter water tub made of vinyl chloride. There was a 15-mm-gap between adjacent electrodes. Electrode 9 was placed at the water surface with 20 mm of its width submerged beneath underwater to observe the discharge current at the water surface. Although there were only two current probes showed in Fig. 1, discharge current observations were done at all electrodes 1–9. The placement and number of electrode were designed to cover all parts of water (i.e. water surface and underwater). The discharge electrode (diameter: 12 mm; tip angle: 45°) was placed 5 mm above the water surface so that there was an air gap between it and the water surface.

A 400 kV impulse voltage generator (Tokyo Transformer, 5 kJ) was used as the voltage source. SDWS was generated by applying a 25 kV peak voltage with a 1.2/50 µs standard lightning impulse voltage. The applied voltage waveform was measured by a resistance divider (voltage dividing ratio 39,882:1) and the current waveforms of all the electrodes were measured by two current probes (Pearson, 6585); displayed on a digital oscilloscope (Tektronix, TDS5054B). Discharge emission images of the water surface were captured using a digital camera (Ricoh, CX3) with an exposure time of 1/7 s. It was orientated at 20° relative to the water surface and faced the discharge electrode. Measurements were conducted by varying the conductivity of water σ by varying the concentration of sodium chloride dissolved in tap water. The conductivity between 0.07 and 10.0 S/m at 25 °C was measured using a conductivity meter (Horiba, ES-51).

In this experimental electrode system, the physical parameter of the electric potential on the water surface is important. To measure the potential, a probe was placed perpendicular to the water surface, where the tip was in contact with the surface as shown in

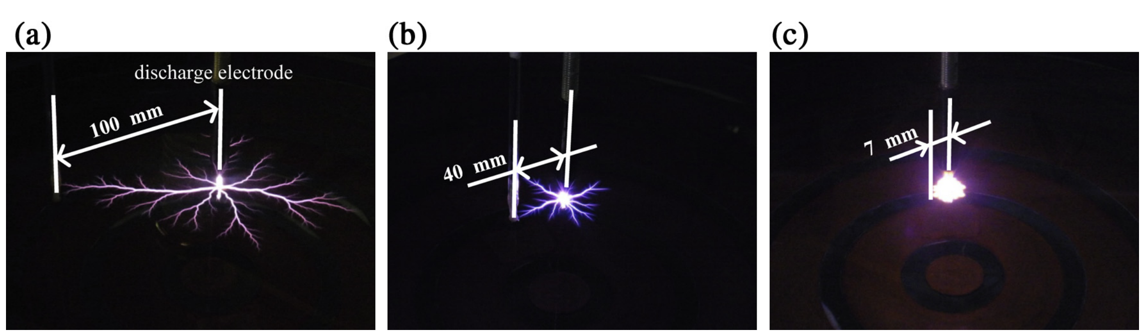

Fig 2. Typical discharge emission profiles on water surface for three values of σ. (a) $\sigma = 0.07$ S/m, (b) $\sigma = 0.2$ S/m, (c) $\sigma = 5.0$ S/m.