Liquid flow induced by atmospheric-pressure dc glow discharge in contact with liquid

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Atmospheric-pressure discharges in contact with liquid are widely applied to water treatment and material processing. In these applications, primary reactions between radicals and liquid molecules always occur at plasma-liquid interface. Since the diffusion in the liquid is very slow, the depletion of chemicals at liquid surface causes the rate-limiting. Therefore, some convective flow is necessary to exchange the chemicals at the plasma-liquid interface for the promotion of efficient reactions. In our previous work, we found the appearance of downward flow in the liquid just below the dc glow discharge in contact with liquid [1]. This downward flow will be effective for exchanging the chemicals at plasma-liquid interface. In this work, we investigated the properties of liquid flow induced by the atmospheric-pressure glow discharge with liquid electrode. The spatiotemporal evolution of the flow was visualized by schlieren method. The fluid simulation was performed to discuss the mechanism of downward force.

Figure 1 shows the experimental setup. Pt wire is immersed in NaCl solution. A stainless-steel nozzle electrode with inner and outer diameters of 500 and 800 μm, is set at about 1 mm above the liquid surface. Helium gas is injected from the nozzle with flow rate of 100-500 sccm. By applying a dc voltage between the nozzle and the liquid electrodes, stable atmospheric-pressure dc glow discharge is generated along the helium flow. The conductivity of the liquid was changed from 10 to 2000 mS/m. Liquid flow was visualized by schlieren method. Temperature distribution in liquid was visualized using micro-encapsulated thermotropic liquid crystal (MTLC) [2].

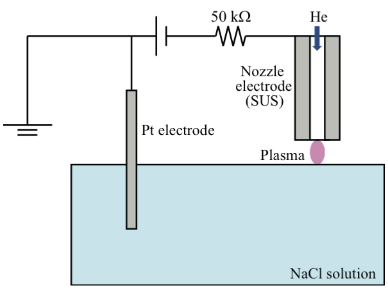

Fig. 1. Experimental setup.

Figure 2(a) shows typical schlieren image in liquid using liquid anode discharge. The downflow appears just below the contacting point of the discharge with liquid surface. From this image, it is considered that some downward force transports the liquid heated at the surface. The heating of the liquid causes the upward flow, and the helium flow from the nozzle promotes the liquid flow in the direction parallel to the liquid surface. Therefore, the downflow is gradually weakened with time. To avoid the contact between gas flow and liquid surface, a sheet made of polypropylene, which has two small holes for glow discharge and Pt wire, is set on the liquid surface. As shown in Fig. 2(b), using the sheet enables the steady downward flow, which means that the downward driving force exceeds the upward buoyancy by heating. We found that the current flow does not influence the liquid flow by changing the position of Pt wire immersed in the liquid. Therefore, some driving force related to the discharge will act on the liquid surface.

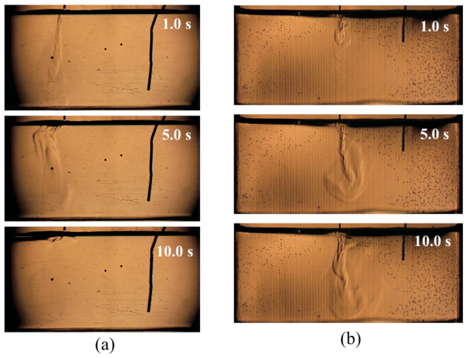

Fig. 2. Schlieren images of liquid anode discharge at 10 mA. (a) normal condition, (b) with sheet to prevent the contact between gas flow and liquid surface.

Axisymmetric 2D numerical simulation of liquid flow was carried out by solving the conservation equations of mass, energy and momentum for incompressible flow using commercial software. The heat source was given as well as the downward driving force due to discharge at liquid surface as a fitting parameter. We have succeeded in reproducing the downward liquid flow. We estimated the magnitude of the force caused by the momentum transfer of charged species at liquid surface. Although the estimated force does not agree quantitatively with the driving force in the simulation, the momentum transfer of electrons/positive ions from plasma at liquid surface is the strong candidate for the driving force of downward flow in liquid.

Acknowledgements

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References

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