Development of Plasma Jet-Based Fluid Surface Stabilization Technology

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Gas jets can create dimple-like depressions in liquid surfaces. As the speed of the gas jet increases, the cavity becomes unstable and starts bubbling and splashing. Despite its scientific and practical importance, little is known about how gas-blown liquid cavities become deformed and destabilized. This study, for the first time, revealed that an ionized gas jet blowing onto water, also known as a 'plasma jet', produces a more stable interaction with the water's surface compared to a neutral gas jet. It found that electrohydrodynamic forces exerted by the plasma jet make the water surface cavity more stable, meaning there is less bubbling and splashing compared to the cavity created by a neutral gas jet. Specifically, the study showed that the plasma jet consists of pulsed waves of gas ionization propagating along the water's surface so-called 'plasma bullets' that exert more force than a neutral gas jet, making the cavity deeper without becoming destabilized. This finding will help improve the scientific understanding of plasma-liquid interactions and their practical applications in a wide range of industrial fields in which fluid control technology is used, including biomedical engineering, chemical production, and agriculture and food engineering.

1. Background (objectives)

Various phenomena appearing at the gas-liquid interface due to the flow of gas are not only being actively utilized in various industrial processes, but also attracting attention in basic and applied research fields. Nevertheless, there was a limit to improving usability due to the lack of thorough understanding of the causes of hydrodynamic instability at the gas-liquid interface due to gas flow. Instability at this interface occurs even when a gas or liquid has electrical properties, such as the Taylor cone caused by electrohydrodynamic instability. However, these liquid interfacial instabilities and related phenomena are caused by multiple causes, and thus remain poorly understood.

2. Contents

In this study, by exploring the basic principle of the generation of electric wind by plasma, it was discovered and succeeded in identifying for the first time that ionized gas or plasma increases the hydrodynamic stability of the interface between gas and liquid. It has been found that when a gas jet with plasma is impinged toward the water surface, the stability of the surface is improved despite the deeper digging of the water surface by the electric wind generated by the plasma. The plasma jet used by the research team in this experiment generates high-speed ionization waves called plasma bullets and electric winds. Through these, it was experimentally confirmed that the instability of the water surface was reduced. After the plasma jet reaches the water surface, a plasma bullet moving at a speed of several tens of km/s along the curved surface of the water generates a strong electric field in a direction parallel to the water surface. Through this electric field and the electrodynamic interaction of the surface of the water, it was the first in the world to investigate the cause of the stable formation of cavities while maintaining the surface of the water due to the increased stability even when the depth of the surface increases. This study also found that the surface of the water became deeper when the pulse width of the voltage applied to create the plasma was increased. Based on these results, it was confirmed that the electrohydrodynamic force by plasma plays a large role in the force applied to the water surface and also improves the stability.

In addition, this research team developed a computational model for the plasma jet and water surface, and theoretically verified the experimentally discovered phenomena. In the developed plasma model, the plasma characteristics were analyzed by calculating the spatiotemporal change of the plasma, and the electric field strength in the direction of the surface increased by the plasma was quantitatively calculated by calculating the electric field near the water surface. From this computational modeling, the experimentally identified improvement in surface stability and deepening of the water surface cavity was cross-validated.

3. Expected effect

The plasma jet used by the research team has recently been utilized for various purposes in diverse interdisciplinary research fields. Therefore, this study will be a useful basis for understanding the interaction between charged particles and neutral particles in weakly ionized plasmas such as atmospheric pressure plasma. In addition, the results of this study are expected to play a major role in expanding the field of plasma fluid control that can be economically and industrially applicable and accelerating various applications.

Furthermore, it is expected that the understanding of the interaction between the plasma jet and the water surface, which has been lacking so far, can make a great contribution to the development and advancement of plasma medicine, life, agriculture, food, and chemical technologies.

Figure 1. Illustration simulating the stabilization of a liquid surface through an ionized gas jet

Figure 2. Video: High-speed shadowgraph movie of water surface deformations induced by plasma impingement

Research outcomes

Paper S. Park, W. Choe, H. Lee, J. Y. Park, J. Kim, S. Y. Moon & U. Cvelbar, "Stabilization of liquid instabilities with ionized gas jets", Nature 592, 49-53 (2021) [2020-21 Impact Factor = 49.962].

Press release 27 domestic media reports, 10 foreign media reports (Science Daily, etc.)
Highlighted in Asia Research News (selected as front cover picture)
Selected as the cover image for the abstract book of the 2021 fall conference of the Korean Physical Society
Promotion on KAIST website and KAIST Breakthrough '21
Article featured in International Low Temperature Plasma Community Newsletter 14

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