Electric wind and water surface stabilization under impingement of a jet plasma: the Electrohydrodynamic story

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An electric wind or ionic wind is a result of direct conversion of electrical energy into mechanical energy of fluids. It is the neutral gas flow that occurs in partially ionized gases due to the electrohydrodynamic force generated by the charged particle drag as a result of the momentum transfer from charged particles to neutrals (Nature Comm. 9 (2018) 371). This phenomenon occurs not only in laboratory plasmas, but also in natural environments such as Earth's ionosphere and the thermosphere and chromosphere of the Sun. There have been numerous efforts to harness the electric wind effect for gas flow control and to propel aircraft without the use of any moving parts. In atmospheric pressure plasmas, the convective flow of neutrals by electric winds can significantly contribute to the transport of radicals. Despite ongoing attempts to apply the electric wind effect, progress in understanding its fundamental science has lagged significantly behind.

Historically, boundary physics has been crucial in understanding a diverse range of phenomena prevalent in nature and in creating highly unusual processes. A good example is the cavity produced by blowing air through a straw directly above a cup of water. One longstanding issue is the hydrodynamic stability of such gas–liquid systems, where some attention has been paid to the formation of gas-blown cavities. However, little attention has been given to the stability of gas-blown cavities, i.e., how the interface is deformed and destabilized remains unknown. For gas-liquid two phase systems, such as water under impingement of a plasma jet, these electric winds also give rise to many interesting physical phenomena. Gas jets can create dimple-like depressions in the liquid surface. As the gas jet speed increases, the cavity becomes unstable and starts bubbling and splashing. Our study, for the first time, revealed that an ionized gas jet blowing onto water produces a more stable interaction with the water surface compared to a neutral gas jet (Nature 592 (2021), 49). It has been found that when a plasma jet is impinged toward the water surface, deeper digging of the water surface occurs by the electric wind generated by the plasma. At the same time, the cavity undergoes a damped oscillation of about 100 Hz, which eventually becomes stable, i.e., the stability of the surface is improved despite the deeper digging of the water surface. We found that the Kelvin-Helmholtz instability becomes stabilized due to the strong electric field parallel to the water surface produced by high-speed ionization waves. The experimental observation was confirmed by computational modelling for the plasma jet and water surface. This case study demonstrates the dynamics of liquids subjected to a plasma-induced force, offering insights into physical processes and revealing an interdependence between weakly ionized plasma and deformable dielectric matter, including plasma–liquid systems.