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Characteristics of pulsed discharges over water surface and their environmental and agricultural applications

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Plasma discharges produce various powerful oxidizing agents, such as hydroxyl radicals and ozone, which have high oxidation potential. These species play an important role in the decomposition of persistent organic compounds in wastewater. Because highly concentrated oxidants are directly produced inside plasma, plasma realizes high speed wastewater treatment without pretreatment of samples such as pH adjustment. The pulsed discharge plasma generated over water surface and inside bubbles is highlighted as a highly efficient method for plasma generation and radical supply into wastewater [1].

Various methods to generate a pulsed discharge in contact with water have been proposed. Figure 1 (a) and (b) show schematic illustrations and photographs of examples. The simplest method is to generate discharge that propagates and spreads over the water surface by using a high-voltage electrode placed above stationary water, as shown in Figure 1 (a). The chemical species generated in the plasma discharge are dissolved into the water and react with organic compounds in the water as described later. The discharges generated inside bubbles as shown in Figure 4 (c), which are produced by injecting gas into water using a gas feed tube, have been widely investigated. This method has advantages such as a high ratio of water surface to gas volume, easy control of the gas purity and components, easy use in various fields and automatic water circulation.

In the plasma generated in the gas phase, various chemically active species such as ozone (O_3), oxygen radicals (O), and hydroxyl radicals (OH) are produced and dissolved at the water surface. Since these species have a high oxidation potential, they can contribute to wastewater treatment, i.e., the decomposition of organic compounds and the inactivation of bacteria. The production reactions are initiated by the impacts of high-energy electrons on neutral molecules. The lifetime and diffusion constant of OH in the gas phase are on the order of 10^{-5} s and 10^{-10} m^2/s, respectively, and the diffusion length is several tens of μm. The lifetime of dissolved OH is on the order of 10^{-6}~10^{-7} s with penetration lengths on the order of 10^{-5}~10^{-6} m.

The decomposition of persistent organic compounds dissolved in wastewater, such as 1,4-dioxane anddichloromethane acid by radicals produced in the plasma discharge is demonstrated, and their mechanisms are discussed. These persistent compounds, which have strong toxicity and stability, can be efficiently decomposed and removed quickly from solutions by plasma treatment as shown in figure 2. Furthermore, the treatment of nutrient solutions used in hydroponic systems for plant cultivation is also introduced as a novel application of plasma, and the effects of bacterial inactivation, decomposition of allelochemicals and improvement in plant growth by plasma are demonstrated as shown in figure 3.

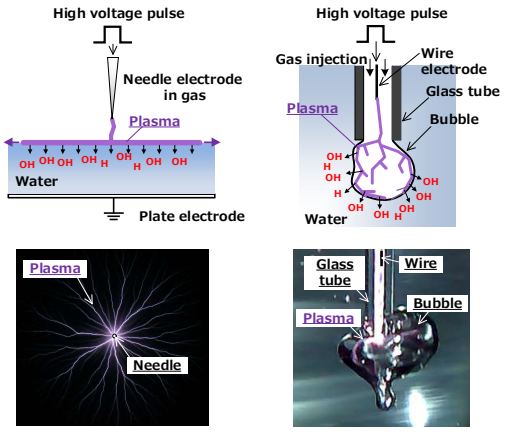

Figure 1 Schematic illustrations and photographs of pulsed discharge in contact with water generated (a) above stationary water surface, (b) inside bubble

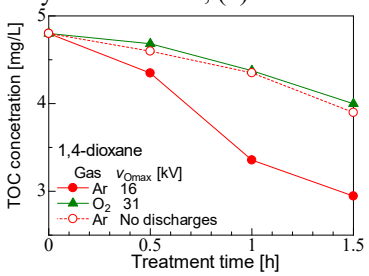

Figure 2 Time change of the TOC concentration of 1,4-dioxane solution by plasma treatment.

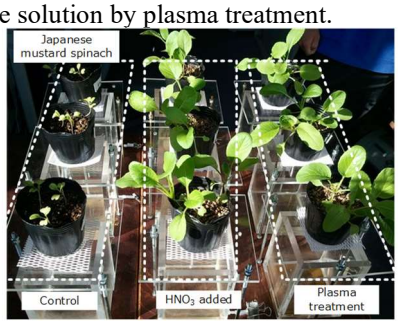

Figure 3 Photograph of Japanese mustard spinach seedlings after 28 days of cultivation using plasma-treated nutrient medium-supplied soil.

References

[1] K. Takahashi, K. Takaki, and N. Satta, "Sewage - Recent Advances, New Perspectives and Applications; Chapt.1 A Novel Wastewater Treatment Method Using Electrical Pulsed Discharge Plasma over a Water Surface", IntechOpen Ltd., London, ISBN 978-1-83969-825-5 (2021.12.10)