9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Numerical Simulation of Methylene Blue Decomposition using a Microplasma Contactor

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Liquid treatment using plasma is expected to be applied to water purification, plasma agriculture, plasma medicine, and new material synthesis. However, most of the proposed techniques have not yet been put into practical use, which may be due to the fact that we have not yet established practical technology capable of treating large amounts of liquid with high efficiency. Large-scale treatment can be achieved by operating equipment in parallel, but to achieve high efficiency, it is necessary to optimize the form of contact between the plasma and liquid.

In the plasma/liquid interface processes, it is believed that OH radicals from the plasma are the main player for decomposition of organic substances in the liquid. However, OH radicals only act in an extremely shallow region just below the liquid surface. For this reason, the authors developed a "Microplasma contactor" as shown in Figure 1 to realize higher efficiency. The main feature of this configuration is that it brings low-voltage-driven plasma as close as possible to a thin liquid.

In this study, we investigated the characteristics of liquid treatment using this microplasma contactor by performing methylene blue decomposition experiments and numerical simulations. The waveform of the H.V was a bipolar square wave with an amplitude of ±5 kV, a frequency of 5 kHz, and a duty cycle of 40%. Discharge gas was argon, of which flow rate was 1 L/min and the pressure relative to 1 atm was +150 Pa. The treatment time was 30 s. In the numerical simulation of liquid-phase reactions, the flux of OH radicals supplied from the DBD plasma was set to a typical value (10^{19} $m^{-2}s^{-1}$) from DBD containing water vapor [1]. The liquid reaction set was based on the reports by Takeuchi *et al* [2] and Vo *et al* [3].

Figure 2 shows the experimental and calculated results of the methylene blue decomposition rate as a function of the liquid thickness. The experimental results show that the thinner the liquid thickness, the higher the treatment efficiency, which indicates that our basic concept is valid for high efficiency.

The calculated results also show a similar tendency. However, the calculated results do not match the experimental results as long as we use normal diffusion coefficients for the chemical species as shown by the dotted line. When the diffusion coefficient was forcibly increased by 100 folds, the calculated results agreed very well with the experimental results. This can be explained by the increase in the effective diffusion coefficient caused by convection [4,5].

On the other hand, even if the OH radical flux is increased up to 100 folds, the methylene blue decomposition rate does not increase as shown in Fig. 3. The marked OH radical flux dependence in the methylene blue decomposition rate is observed only when the OH radical flux was quite small.

These results indicate that when aiming to improve the efficiency of liquid treatment using plasma, it is more effective to promote convection when the plasma supplies sufficient OH radicals into the liquid.

Acknowledgements
This work has been supported by the MEXT/JSPS KAKENHI (23K25863, 24K21542), and the Joint Usage / Research Program of Center for Low-Temperature Plasma Science, Nagoya University.

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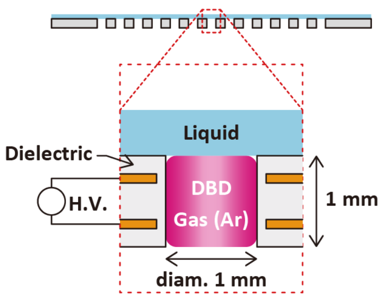

Fig. 1 Schematic illustration of the concept of a microplasma contactor.

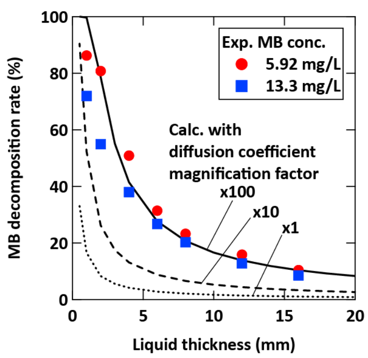

Fig. 2 Measured and calculated MB decomposition rate as a function of liquid thickness.

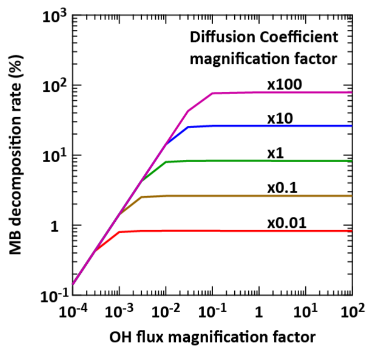

Fig. 3 Effects of the flux of OH radicals and diffusion coefficient of liquid species on MB decomposition rate.