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Atmospheric pressure plasma generation using superimposed voltage waveform pulsed-power supply and treatment of *Escherichia coli*

電圧波形重畳型パルスパワー電源を用いた
大気圧プラズマの生成と大腸菌処理効果の検討

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In this study, we have demonstrated effects of atmospheric pressure plasma generated by superimposed voltage waveform pulsed-power supply on treatment of *Escherichia coli* (*E.coli*). The growth rates of *E.coli* irradiated by plasma without or with superimposing sustained voltage waveform were compared. The irradiation of atmospheric pressure plasma without superimposing sustained voltage waveform decreased the growth rates of *E.coli*. On the other hand, the irradiation of atmospheric pressure plasma with superimposing sustained voltage waveform recovered the decrease of the growth rates of *E.coli*. These results suggest that the superimposing sustained voltage waveform has the potentially positive effects on the growth rates of *E.coli*.

1. Introduction

Atmospheric pressure plasma is applied to various fields such as medical treatments, surface modifications, and environmental improvements [1]. Dielectric barrier discharge (DBD) plasma is one of the plasma generation methods. DBD plasma generates dense active species without vacuum, and it can be treated without heat damage. Therefore, DBD plasma is applied to non-thermal treatment of medical equipment and microorganisms [2].

Atmospheric pressure plasma may enable to stimulate growth of microorganisms [3]. Growth rates of microorganisms affect the electric stimulus such as electric fields [4]. It suggests that the plasma and pulsed-power discharge will control growth rate of microorganisms. In this study, we have demonstrated effects of atmospheric pressure plasma generated by superimposed voltage waveform pulsed-power supply on treatment of *Escherichia coli* (*E.coli*).

2. Experimental procedures

2.1 *Experimental apparatus*

Schematic diagram of plasma treatment apparatus to generate DBD plasma is shown in Fig. 1. The experimental apparatus consists of a pulsed-power supply providing superimposed voltage waveform, a dielectric made by alumina (200×100×1 mm), cultivated *E. coli* on a dish (ϕ 60×25 mm), an upper electrode made by aluminum (30×30×20 mm), a lower electrode made by aluminum (ϕ 60×25 mm), and introducing system for helium gas to generate atmospheric pressure plasma. The DBD plasma was generated in between the upper electrode and the culture medium.

Output voltage waveform of superimposed voltage waveform pulsed-power supply is shown in Fig. 2. This supply can output a high-voltage pulse superimposed low-voltage pulses. The high-voltage pulse generates ionization of atoms or molecules in the ambient air and the low-voltage pulses sustain generated plasmas by the electric field. The

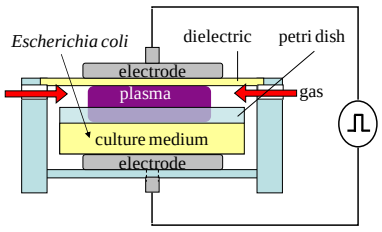

Fig.1 Experimental apparatus

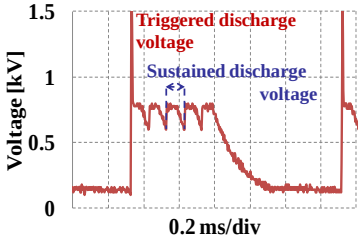

Fig. 2 Output of superimposed voltage waveform pulsed-power supply

high-voltage pulse defines “triggered discharge voltage” and this low-voltage pulse also defines “sustained discharge voltage”.

2.2 *Evaluation of plasma treatment effects*

Plasma treatment effects was estimated by a change in growth rates of *E.coli*. *E.coli* was incubated until a logarithmic growth phase (37℃, 170 min^{-1}). *E.coli* was irradiated by the plasma within the logarithmic growth phase, and its irradiation duration was 30 min. Growth rates of *E.coli* are estimated by the optical density (O.D.). Optical density was measured using a spectrophotometer (HITACHI U-1100) for every an hour. Optical density is calculated by eq. (1) as follow,

$$\text{O.D.} = -\log\left(\frac{I}{I_o}\right) \quad (1)$$

where, I_0 is the incident light, and I is the light through the suspention. Plasma treatment effects with superimposed voltage waveform were compared to that without superimposed voltage waveform.

3. Results and Discussion

3.1 *Plasma treatment effects without superimposed voltage waveform*

A trigger discharge voltage of 14 kV with 200 ns was applied to generate DBD plasma, and the voltage set to 800 pulse/s in this study. *E.coli* suspension was measured the optical density after was irradiated the plasma for 30 minutes. Growth rate of *E.coli* as a function of time is shown in Fig. 3. Growth rates of *E.coli* without plasma irradiation are 0.315 h^{-1}, and that with plasma irradiation are 0.148 h^{-1}. It indicated that the growth rates of *E.coli* are decreased by plasma irradiation without superimposed voltage waveform.

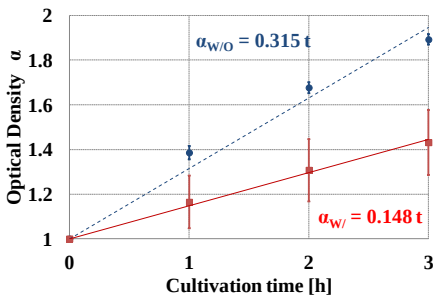

Fig. 3 Treatment effect on *E.coli* without superimposed voltage waveform for n = 3, mean ± SE.

3.2 *Plasma treatment effects with superimposed voltage waveform*

The applied voltage for DBD plasma generation consists of the trigger discharge voltage and 5 sustained discharge voltages. The sustained discharge voltage is 0.8 kV with 100 μs of the pulse duration. The optical density of *E.coli* suspension was observed after 30 min of plasma irradiation. Growth rates of *E.coli* are shown in Fig.4. Growth rates of *E.coli* with plasma irradiation are 0.303 h^{-1}, and that without plasma irradiation are 0.315 h^{-1}. Growth rates of *E.coli* with plasma irradiation are similar with that without plasma irradiation. It means that the sustained discharge voltage affects the growth rates of *E.coli*.

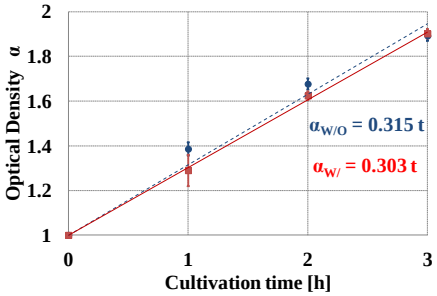

Fig. 4 Treatment effect on *E.coli* with superimposed voltage waveform for n = 3, mean ± SE.

4. Conclusion

Effects of atmospheric pressure plasma generated by superimposed voltage waveform pulsed-power supply on treatment of *E.coli* were demonstrated. The plasma without superimposing sustained voltage waveform decreased the growth rates of *E.coli*. However, the plasma with superimposing sustained voltage waveform recovered the decrease of the growth rates of *E.coli*. Therefore, modification waveform as the superimposed waveform affects the growth rates of *E.coli*. The superimposing sustained voltage waveform has the potentially positive effects on the growth rates of *E.coli*.

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