Development of novel air purification technology using ions generated by discharge plasma: (i) physical background and biological effect on indoor air quality

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ABSTRACT

A novel indoor air purification technology using ions generated by discharge plasma has been developed. With the application of AC voltage between electrodes, discharge plasma has been occurred and positively charged ions and negatively charged ions have been generated at atmospheric pressure. The chemical compositions of the ions have been clarified to $H^+ (H_2O)_m$ and $O_2^- (H_2O)_n$ by time-of-flight mass spectroscopy. Bacteriostatic and fungistatic effects of these ions have been investigated. All four bacterial test strains used in this study have been inhibited in their re-growth capacity. The fungi have been inhibited in their germinating capacity with the use of this technology.

INDEX TERMS

Microorganism; Air quality; Indoor air; Ion; Discharge plasma

INTRODUCTION

The application of discharge plasma at atmospheric pressure for indoor air purification has been studied intensively (Oda, 2000). The discharge plasma generates various active species such as radicals and ions. The radicals have high chemical activities and several mechanisms of reactions on harmful molecules are reported (Chang, 1989; Matzig, 1991). On the other hand, the characteristics of plasma-generated ions at atmospheric pressure are not yet clear.

In this paper we report the development of novel air purification technology using ions generated by discharge plasma. We describe the physical background of this technology and effect on indoor air quality in particular microorganisms.

PHYSICAL BACKGROUND

Ion-generation Device

The developed ion-generation device consists of a ceramic dielectric plate and attached inner and outer electrodes. Figure 1 shows the photograph of the ion-generation device. The schematic cross-sectional diagram is shown in Figure 2. With the application of AC voltage between the electrodes, discharge plasma occurs at the surface of the ceramic plate and positively and negatively charged ions are generated at atmospheric pressure. The concentration of ozone is confirmed to be less than 0.005 ppm in the vicinity of the device.

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Fundamental Properties of Ions

The chemical compositions of the generated ions have been examined by time-of-flight mass spectroscopy. Figure 3 shows the mass spectra of the ions generated from the developed device. As shown in this figure, it has been found that the positive ion is H^+ surrounded by water molecules, $H^+(H_2O)_m$, and the negative ion is O_2^- surrounded by water molecules, $O_2^-(H_2O)_n$. Schematic structures of the ions are shown in Figure 4. The ion densities are examined by measuring electrical conductivity of air using a double co-cylinder shaped detector, called a Gerdien condensor. The densities of positive and negative ions are almost same amounts and are about 5×10^4 counts/cm^3 at a distance of 10 cm from the surface of the ion generation device. The lifetimes of these ions have also been measured. The lifetime has been obtained to be approximately 3–5 s in air for both positive and negative ions.

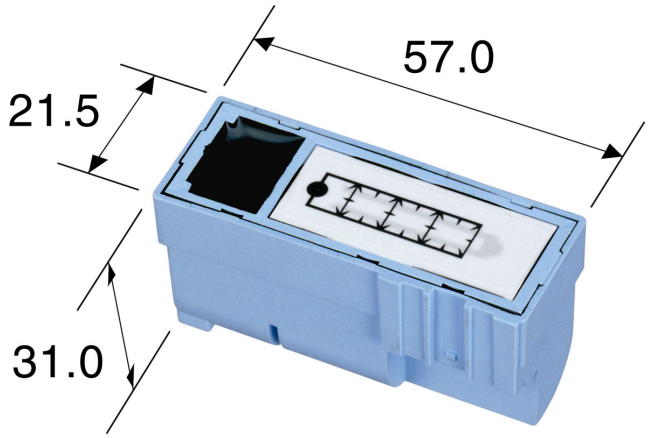

Figure 1 Ion-generation device (mm).

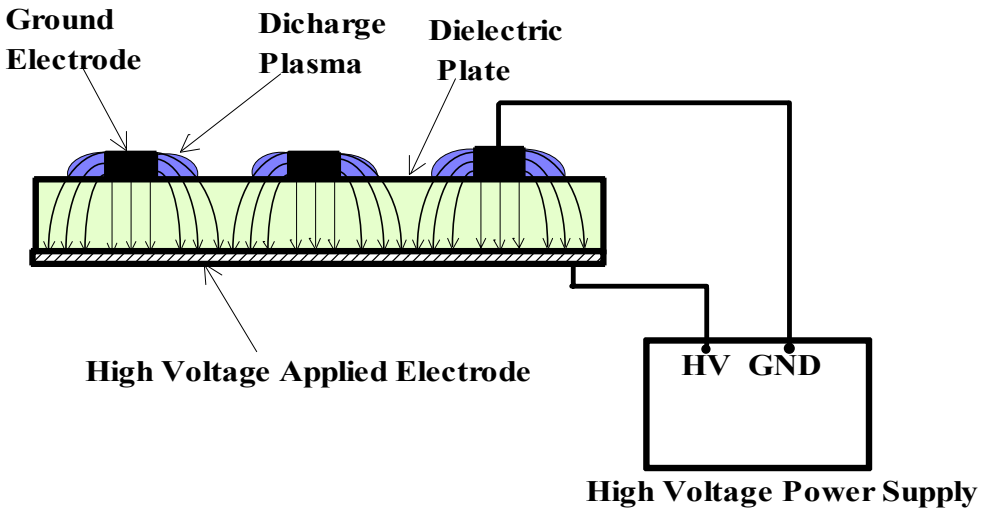

Figure 2. Schematic cross sectional diagram of ion generation device

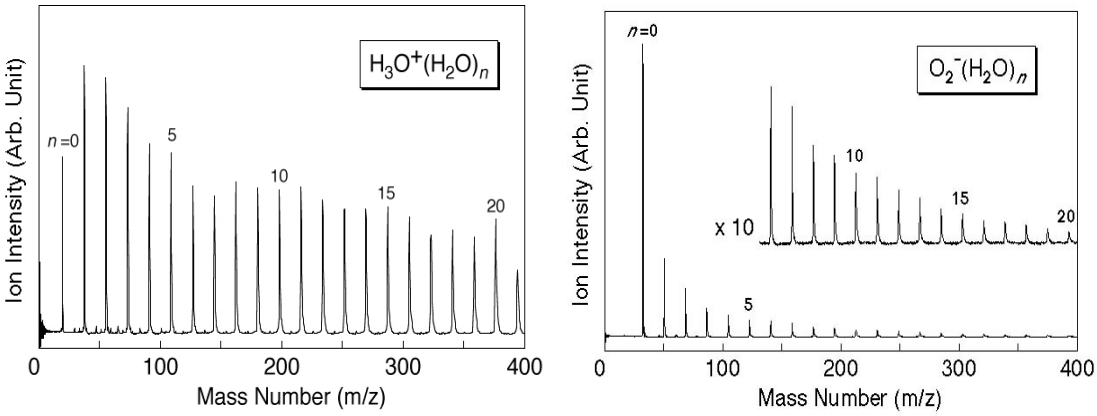

Figure 3 Mass spectra of generated ions (left, positive ions; right, negative ions).

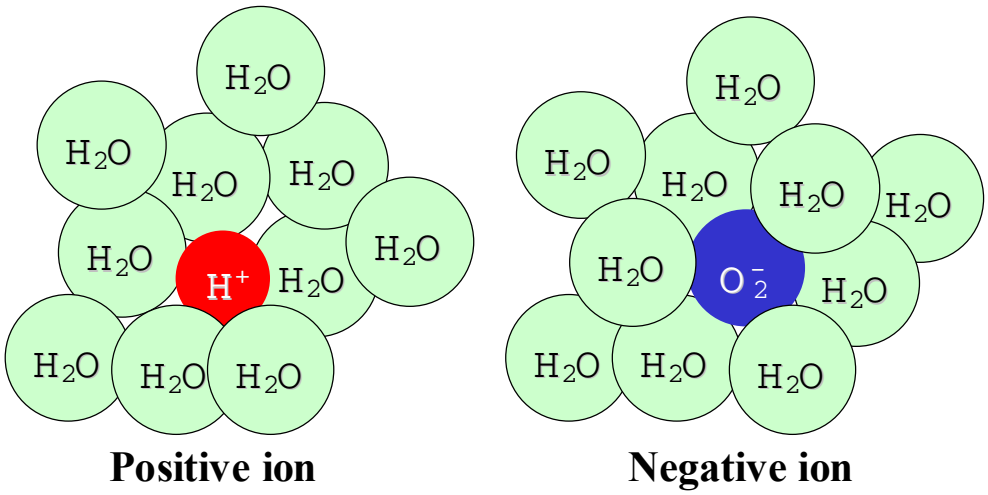

Figure 4 Schematic structure of the ions generated by the developed device.

BIOLOGICAL EFFECT

Methods

To clarify the effect of these ions on indoor air quality in particular microbials, the growth inhibiting action of selected microorganism (bacteria and fungi) under the influence of the ions has been investigated. The bacteriostatic effect of the ions with simultaneous culture in a climate-controlled test chamber (dimensions: 41 × 41 × 41 cm: volume: approximately 69 l) was examined. As test bacteria, *Staphylococcus epidermidis* (ATCC 1228), MRSA (methicillin-resistant *Staphylococcus aureus*, ATCC 33591), *Escherichia coli* (ATCC 11229), *Enterococcus faecim* (ATCC 6057) were used. The open culture media were exposed to the ions for 24 h at a temperature of 36°C (maximum 39°C). To guarantee an a_w (water activity) value between 0.7 and 0.8, a saturated sodium acetate solution, poured into a tank at the bottom of the test chamber (approximately 1.5 l), was used. The fungistatic effect of the ions on the germination capacity of fungal spores was examined by means of a modified ASTM C665 test (ASTM = American Society of Testing and Materials).

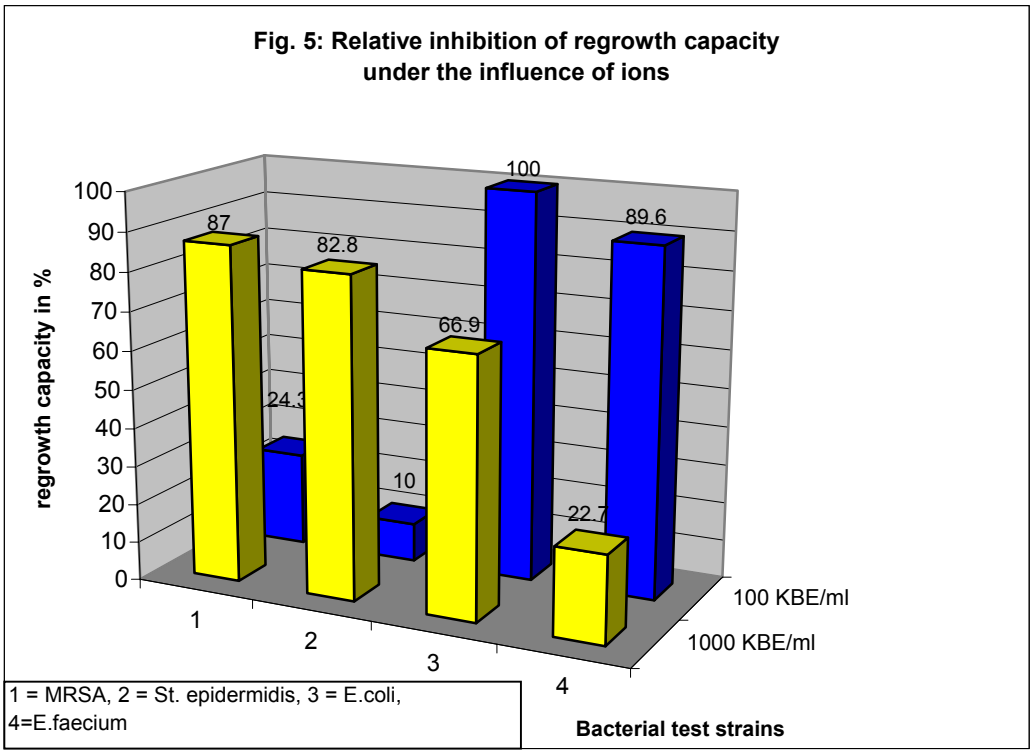

Figure 5

RESULTS

All four bacterial test strains used were inhibited in their re-growth capacity under the conditions provided. The relative inhibition of re-growth capacity with the influence of ions, is shown in Figure 5. The exposure of ions on the four selected bacterial test strains, with an action time of 24 h and simultaneous incubation at 36°C (maximum 39°C) produced a bacteriostatic effect on their re-growth capacity. Among the test strains *Staphylococcus epidermidis*, MRSA, *Escherichia coli* and *Enterococcus faecium*, the ion treatment displayed gradually differing effects. The growth inhibition of *Staphylococcus epidermidis* was most recognizable.

Additionally, it was found that the fungi (*Penicillium expansum*, *Aspergillus fumigatus* and *Cladosporium herbarum*) were inhibited in their germinating capacity with the use of these ions.

DISCUSSION

In the experiments described above, the ions generated by discharge plasma showed bacteriostatic and fungistatic effects. In addition, two of the authors (Nishikawa and Nojima, 2001) already reported the efficacy of the ion generation device to reduce the airborne concentration of *Escherichia coli*. In their study, the airborne *Escherichia coli* count decreased to 18% after 60 min operation of the ion-generation device compared with the control test.

As a possible explanation for the obtained bacteriostatic and fungistatic effects of the ions generated by discharge plasma, it is considered as follows. When the generated ions collide with bacteria or fungi spores, positively charged ion $H^+(H_2O)_m$ and negatively charged ion $O_2^-(H_2O)_n$ react on the bacteria or fungi and generate some active species, for

example HO_2, H_2O_2 and OH radicals. These active species probably break the cell membranes on microorganisms. As a result the ions have bacteriostatic and fungistatic properties. The schematic picture of this explanation is shown in Figure 6. We are now investigating the mechanism of these characteristics with atom-scale techniques.

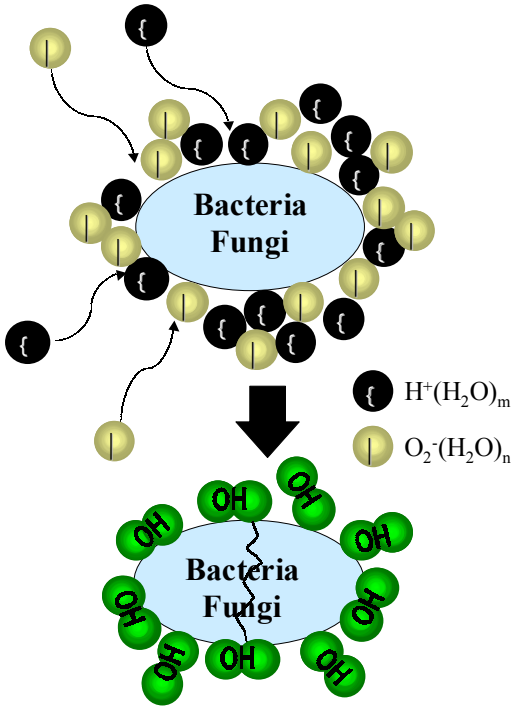

Figure 6 Schematic picture of bacteriostatic and fungstatic characteristics of the ions.

CONCLUSIONS

We have developed novel air purification technology which uses ions generated by discharge plasma. The chemical compositions of generated ions have been confirmed to $H^+(H_2O)_m$ and $O_2^-(H_2O)_n$ by time-of-flight mass spectroscopy. The growth-inhibiting action of selected microorganism (bacteria and fungi) under the exposure of the ions has been investigated. The exposure to the ions has produced a bacteriostatic effect on their re-growth capacity. It has been found that fungi are inhibited in their germinating capacity by the ions. A possible explanation for the obtained bacteriostatic and fungistatic effects of the ions is proposed in brief.

ACKNOWLEDGEMENTS

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