ENHANCEMENT MECHANISM OF PLASMA COUPLED CATALYSIS FOR PURIFICATION OF AIRBORNE MICROBIAL AEROSOLS: SYNERGISTIC MECHANISM OF ELECTROPORATION AND CATALYTIC OZONATION

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ABSTRACT

This study investigates the enhancement mechanism of plasma coupled catalysis (PCC) for the purification of airborne microbial aerosols, focusing on the synergistic effects of catalytic ozonation and electroporation. Utilizing a corona discharge plasma coupled with a modified Al-$MnCeO_x$ honeycomb electrode, the system demonstrates high efficiency in microbial inactivation, achieving over 99% purification. The study explores the dominant role of electroporation in disrupting microbial structures through high electric field strengths (up to 8.24×10^6 V/m) while examining the catalytic effects of ozone. Detailed analyses of the electrode's surface morphology and electrostatic properties reveal critical factors contributing to its superior disinfection performance. The PCC system shows promise for specialized air disinfection applications, particularly in environments requiring sterile conditions.

KEY WORDS

Plasma coupled catalysis, Microbial aerosol, Electroporation, Catalytic ozonation, Synergistic mechanism

1. INTRODUCTION

In recent years, there has been growing interest in the application of plasma coupled catalysis (PCC) for the purification of microbial aerosols, driven by advancements in both plasma technology and catalytic materials. Although the PCC has been widely employed in environmental pollutants abatement, there are still no reported works about the application of plasma coupled catalysis in inactivation of airborne microbial aerosols. Generally, DBD coupled with catalytic materials has been widely researched. While a notable concern is the strong reliance on an external AC power supply, which limits the application of the methods. Moreover, the discussion of ozone oxidation inactivation and electroporation is still blank.

2. RESEARCH METHODS

2.1 Plasma Coupled Catalysis air disinfection methods.

A comprehensive air purification process that combines electrical charging, particle trapping, and inactivation. Air containing microorganisms enters from the left, where high-voltage DC imparts a negative charge to particles, ensuring a uniform charge that enhances capture efficiency. The charged particles then move to a honeycomb-like trapping medium, connected to ground, which serves as the filtration site. This design maximizes surface area for particle collection. Finally, a catalytic electrode captures and neutralizes the particles, ensuring they are inactivated and safely contained.

2.2 Synthesis and characterization of Aluminum-based catalyst

Analytical-grade chemical reagents were sourced from SINOPHARM and used without modification. The aluminum honeycomb (sheet thickness: 0.04 mm, hole diameter: 1.5 mm, section size: π*35*35 mm^2) underwent a pretreatment process — degreasing with acetone, etching in 2 M NaOH to remove Al_2O_3, and rinsing with deionized water. Al-MnO_x was then synthesized by placing the pretreated honeycomb in an 80 mL solution of 5 mM $KMnO_4$ at 160 °C for 12 hours. Al-$MnCeO_x$ followed a similar method with an additional 1 mM $Ce(NO_3)_3$ solution.

2.3 Numerical simulation for the electrostatic field

Details about the numerical simulation is presented in Supporting information.

3. RESULTS AND DISCUSSION

3.1 Disinfection performance

The figures analyze ion generation, ozone concentration, and microbial inactivation in air purification systems across different catalytic materials and setups. Fig. 1a shows a bar graph of particle collection efficiency from 4 kV (25±0.05%) to 6 kV (99±0%) for 0.65-1 μm particles, with error bars reinforcing data reliability. Fig. 1b reveals that, while ion concentration boosts purification efficiency, the inactivation rate from 4 kV (49.35±1.18%) to 8 kV (86.6±6.11%) rises slower than particle collection. This highlights the different mechanisms involved in trapping

particles versus purifying aerosols.

Fig. 1c presents a dual-axis chart correlating ozone concentration and microbial purification efficiency across aluminum electrodes. The highest efficiency appears with $MnCeO_x$ (98.77±1.18%) but suggests a trade-off between ozone levels and purification effectiveness. Wang et al. found that MnO_x converts ozone to other ROS, aiding in microbial inactivation. However, $MnCeO_x$ shows minimal ozone depletion, implying that catalytic inactivation might not rely heavily on ozone reduction.

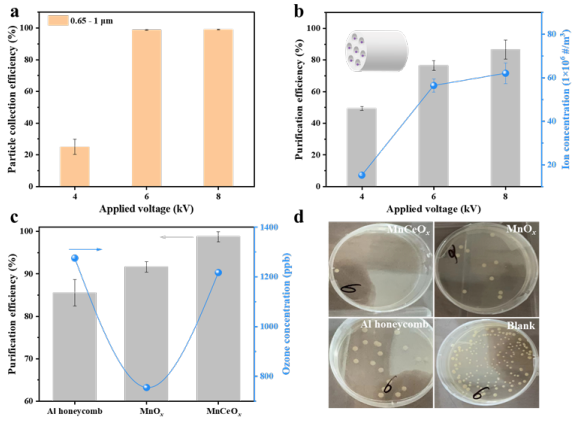

Fig. 1 (a) Collection efficiency of aerosol particles (NaCl) with 0.65-1 μm (1 m/s); (b) inactivation efficiency of the single charger and the ion concentration detected (1 m/s); (c) inactivat
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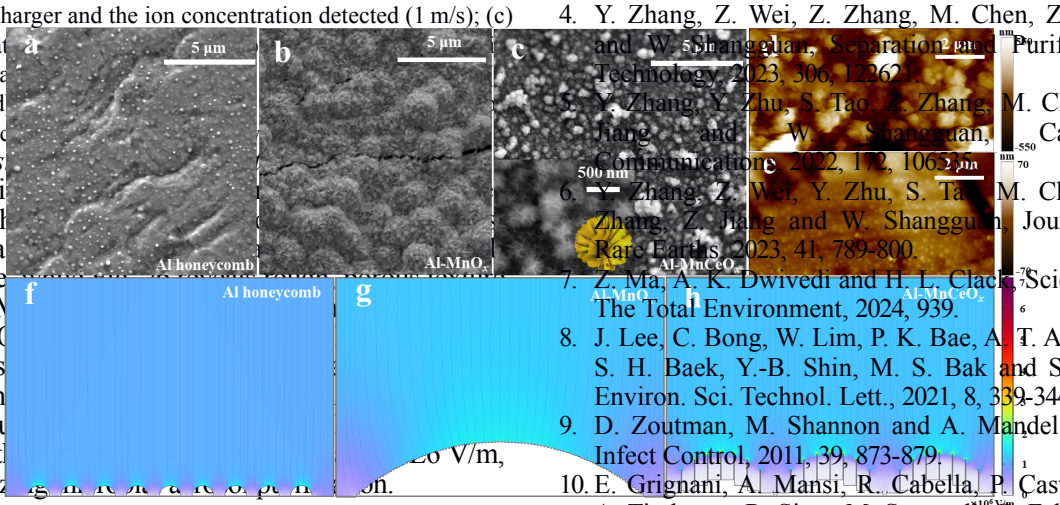

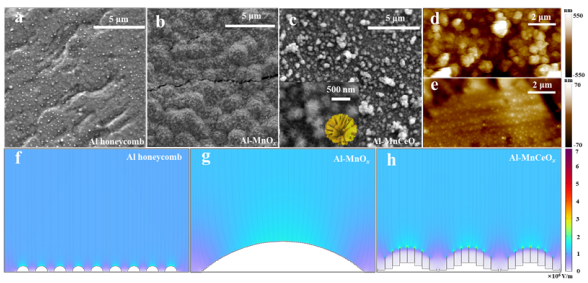

Fig. 2. Micro structure analysis of the modified electro de. SEM results of (a) Al-honeycomb, (b) Al-MnO_x, (c) Al-$MnCeO_x$. Atomic force microscope (AFM) results of (d) Al-$MnCeO_x$ and (e) Al-honeycomb. Electric field strength distribution on the surface of (f) Al-honeyco mb, (g) Al-MnO*x* and (h) Al-MnCeO*x*.

4. CONCLUSION

The study presents a novel plasma coupled catalysis (PCC) system for airborne microbial aerosol purification, utilizing a modified Al-$MnCeO_x$ honeycomb electrode. The system's efficiency is enhanced through a combination of electroporation and catalytic ozonation, although the results suggest electroporation plays a more dominant role in microbial inactivation. With a high electric field strength (up to 8.24×10^6 V/m) and efficient particle collection, the PCC system achieves over 99% inactivation of microbial aerosols, making it an effective solution for environments requiring rapid air disinfection. However, the system's reliance on ozone suggests its application is more suitable for specialized settings such as operating rooms rather than general household use.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (52200130, 22176123).

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