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Generation of High-Speed Water Nanodroplets and Their Applications

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Water is an essential resource, and the 21st century faces escalating water-related challenges driven by industrial expansion, changing lifestyles, and climate change. Addressing these issues demands not only conservation but a fundamental rethinking of how water is utilized. Conventional cleaning technologies typically depend on large volumes of water and often incorporate chemical agents, both of which pose sustainability concerns.

This study presents a groundbreaking approach using high-speed nano droplets formed by condensing water vapor within pressurized air ejecting with high velocities. Unlike traditional sprays, these droplets can sterilize and clean surfaces without chemicals and without leaving residual moisture or wetting, thereby enabling significant water savings and environmental benefits.

The generation system (Fig. 1) heats pure water in a sealed container to the boiling point at 5 atm [1]. When issued through a nozzle, a supersonic flow is formed (Fig. 2 Left) and the vapor condenses into nano-sized droplets (Fig. 2 Right). The traveling velocity and temperature decrease down to 50–60 m/s and ~40°C, respectively, at approximately 40 mm from the nozzle, making it suitable for safe surface application. Although the droplets are invisible with naked eyes, an ultraviolet laser scattering visualizations show the individual droplets exist in the jet.

These nanodroplets exhibit exceptional cleaning performance. When applied to the medical cleaning process indicators coated with organic films, they successfully removed over a width of 3 mm within just 1 second (Fig. 3 Left); an effect not observed with air jets alone. Laser microscopy revealed the formation of micro-craters approximately 300 nm in diameter and 500 nm in depth (Fig. 3 Right), indicating that the cleaning mechanism is probably driven by the mechanical impact of droplets, rather than heat or airflow alone.

In sterilization trials, the technique demonstrated high efficacy against Staphylococcus aureus biofilms formed on artificial blood vessels. Conventional chemical soaking (Fig. 4 Left) and a high-pressure gas jet (Fig. 4 Center) failed to remove the biofilms. In contrast, the nanodroplets completely eliminated the biofilm, even within deep fibrous structures, without damaging the underlying material (Fig. 4 Right). Even gram negative bacteria are sterilized in 240 s at maximum [2] This highlights the method's potential for safe sterilization in biomedical and other sensitive applications.

Importantly, this approach relies solely on water that no chemical additives or detergents are required and leaves surfaces clean, sterilized, and dry. It represents a paradigm shift in water-based cleaning, with broad implications for medical, industrial, and environmental sectors.

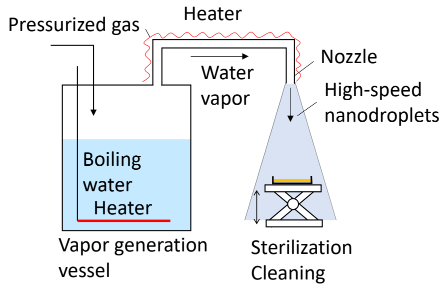

Fig. 1 High-speed nanodroplets generation device.

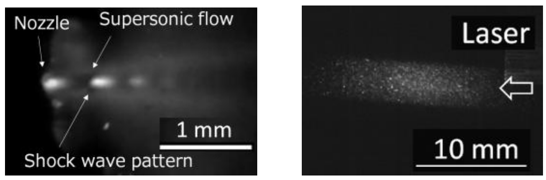

Fig. 2 (Left) Supersonic flow imaged by Schlieren method. (Right) Imaging using the UV pulse laser [3].

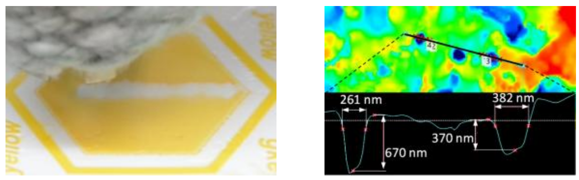

Fig. 3 (Left) Cleaning effect on the medical cleaning process indicator (5 mm): the removal area as shown in white, (Right) Surface profile analysis on the indicator.

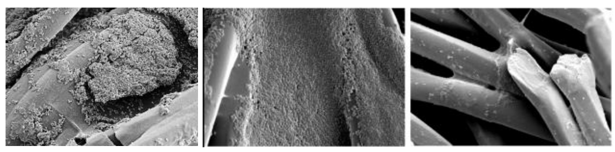

Fig. 4 Effects of treatments on biofilm-formed bacteria on artificial blood vessel [3]. High-speed nanodroplets generation device. (Left) Antimicrobial agent (24 h), (Center) High pressure gas (5 s), (Right) Nanodroplets (5 s).

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References

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