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宇宙での殺菌利用に向けた空気ウルトラファインバブルの発生挙動

Generation Behavior of Air Ultra Fine Bubbles for Sterilization Application in Space

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1. Introduction

Astronauts' urine and condensate from the air conditioner in the International Space Station are purified and recycled for reuse as drinking water. In this process, disinfectants such as silver ions or iodine are added to the reclaimed water to prevent the growth of bacteria. However, since they are consumables, they need to be replenished periodically, which is a costly problem. In a human lunar exploration, the mission will be conducted far from the earth. So, frequent transportation will be difficult, so consumables must be reduced as much as possible. Therefore, we focused on a sterilization method using ultra fine bubbles (UFBs), which are nano-scale bubbles. In the existing research, ozone UFBs generated by mixing ozone are used for sterilization by the oxidizing effect of ozone. The mechanism of UFB generation and disinfection has not been clarified yet, although the generation and disinfection effects have been found experimentally. The purpose of this study is to clarify the dominant factors of UFB generation, and to identify the conditions for higher number density using flow rate and generator passage time as parameters, as well as to search for the optimum conditions for sterilization.

2. Experiment

2.1 Experimental apparatus

Figure 1 shows a schematic diagram of the apparatus used in this experiment. After filling the tank with 4 L of ultrapure water, a pump was used to circulate the water at a constant flow rate for a specified time. The pump was stopped, and the ultrafine bubble water (UFB water) generated in the tank was sampled using a syringe, and the bubble diameter and number density were analyzed by the nano particle tracking method (NanoSight LM10V-HS). The dissolved oxygen concentration and water temperature before and after UFB generation were measured with a dissolved oxygen meter (DO-31P, manufactured by Toa DKK) in order to determine the amount of dissolved air in the water in the tank. Two types of UFB generators with different generation principles were used in this study.

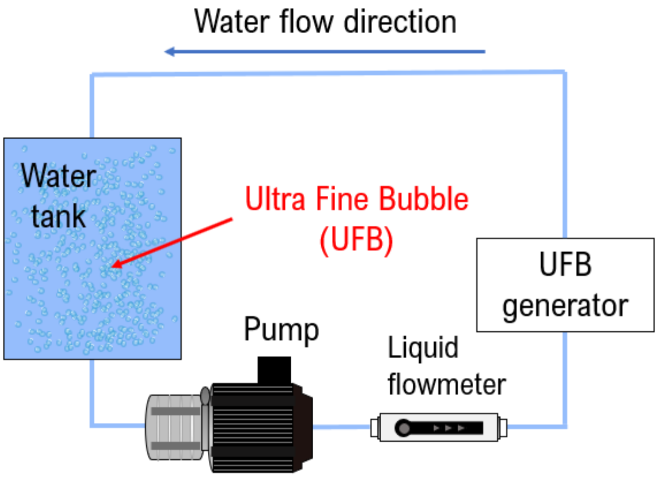
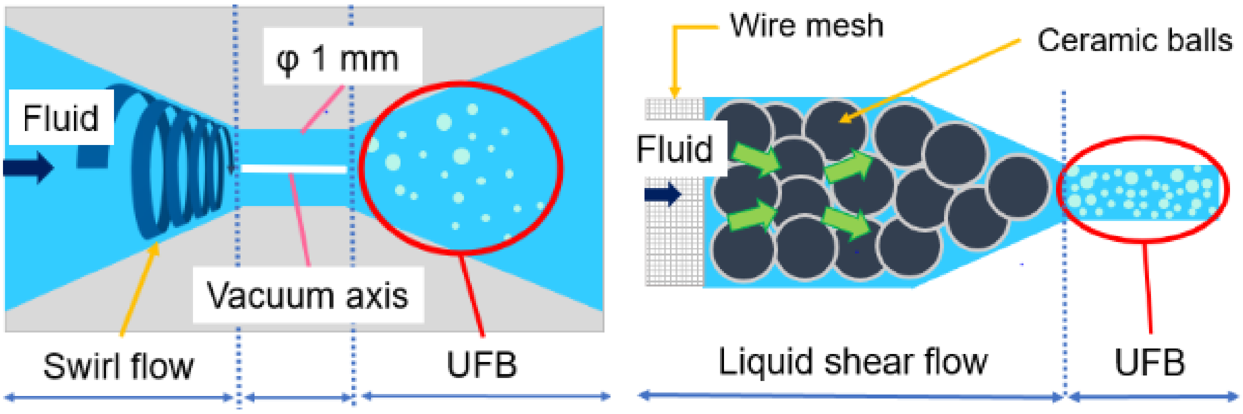


Fig. 1 Schematic of experimental apparatus

2.2 Principle of UFB generation [1)]

Figure 2 shows a schematic diagram of the internal structure of the UFB generator. Both methods use dissolved air in the water to generate bubbles. Figure 2 (a) shows a UFB generator (UFB-4GMN) that combines the swirl flow and cavitation methods (Cyclone & Cavitation system). Figure 2 (b) shows a static mixer type generator (MK-173). When the water passes through the wire mesh and ceramic balls, large bubbles are generated by the shear flow, and then decompression boiling occurs to generate UFB in the water. (Static mixer system).



(a) Cyclone & Cavitation system (b) Static Mixer system

Fig.2 Schematic of two types of UFB generator

2.3 Experimental conditions

The following three experimental conditions were set up, and the diameter of UFB and the UFB number density was measured under each condition.

(1) Effect of generation method and flow rate

The flow rate through the UFB generator was set to a constant value between 1 to 7.5 L/min for the Cyclone & Cavitation system and cavitation type, and between 1 to 10.5 L/min for the Static Mixer system, and the UFB-containing water was circulated for 3 minutes.

(2) Effect of initial dissolved gas concentration

Water containing UFB generated using ultra purified water with an initial dissolved oxygen content of 62% (5.5 mg/L of dissolved oxygen concentration) and 71% (6.3 mg/L) of the saturated dissolved oxygen content in the water is measured and metered. The flow rate is 7.5 L/min, the circulation time is 3 minutes, and the water temperature is at 20°C.

(3) Effect of circulation time

The number of passes through the UFB generator was set in the range of 1 to 45 times by changing the circulation time through the UFB generator, and the generated UFB-containing water was measured.

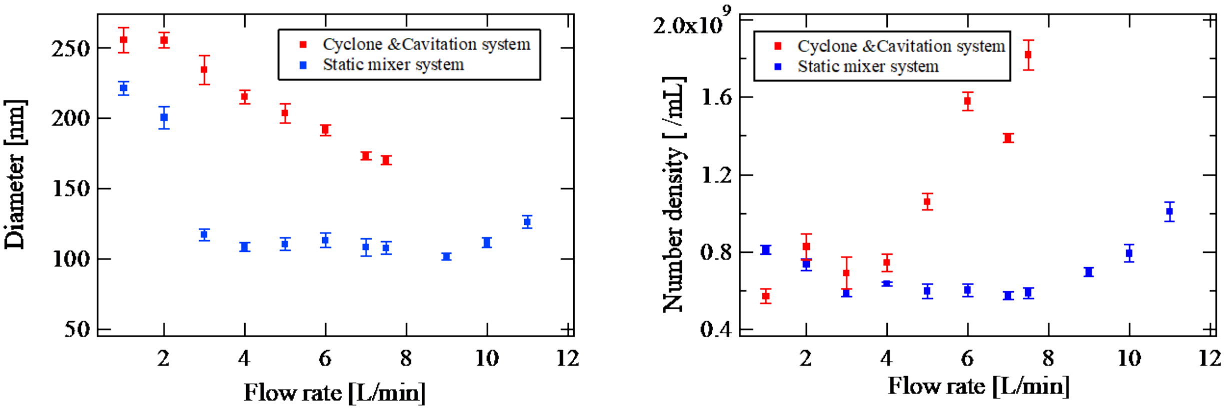
(4) Effect of time after generation

Water containing UFBs was placed in a 100-mL container and diluted with 1 mL of sodium hypochlorite to prevent the growth of bacteria in the container. The number density and bubble diameter were measured immediately after UFB generation (10 min) and every 24 hours for a week. After that, the samples were stored in a sealed container to prevent the influence of air, and kept in a refrigerator (6-7 °C) except when measuring to prevent the growth of bacteria in the container. At the same time, ultrapurified water without UFB generation was prepared and measured under the same conditions.

3. Results and discussion

3.1 Effect of generation method and flow rate

Figure 3 shows the results of the number density of particles at each flow rate. The bubble diameter decreases with increasing flow rate. The average bubble diameter generated by using the Static Mixer system is about 50 nm smaller than that by the cavitation type at the same flow rate. It was found that the number density increased with increasing flow rate in the Cyclone & Cavitation system, did not change significantly in the static mixer system. These results indicate that the number density of bubbles generated using cavitation is higher than that of bubbles generated using shear flow at the flow rates measured in this study.

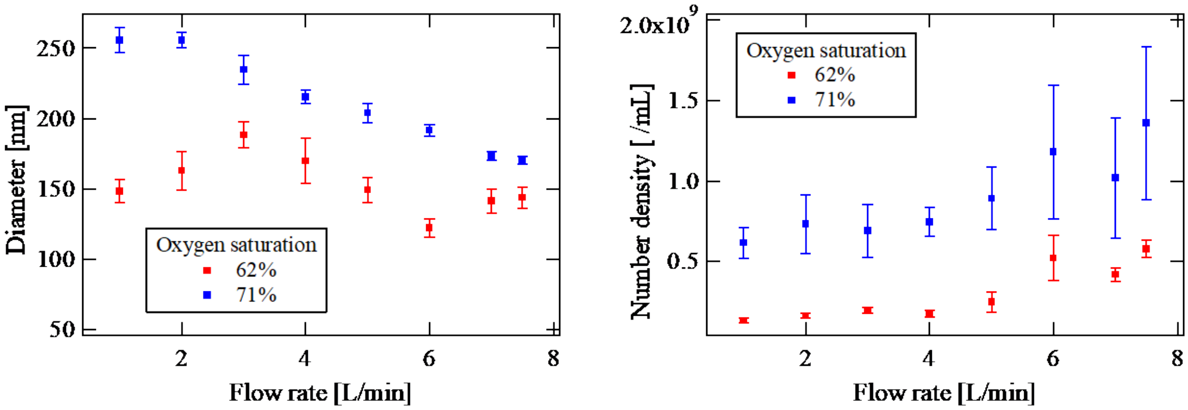


(a) Effect on bubble diameter (b) Effect on number density

Fig. 3 Effect of flow rate and generation system

3.2 Effect of initial dissolved gas content

The effect of the initial dissolved oxygen concentration was investigated by measuring the number density and bubble diameter of the generated UFBs with variety of two kinds of initial dissolved oxygen concentration. The number density and bubble diameter of the UFBs generated by using two kinds of oxygen concentration in ultra-purified water are shown in Fig. 4. In this study, the number density was 62% of the saturated dissolved oxygen (initial dissolved oxygen content is 5.5 mg/L), and the blue plot showed 71% of the saturated dissolved oxygen (6.3 mg/L). According to the graphs, it was found that the average bubble diameter was smaller when water in a smaller oxygen content, and that the average bubble diameter became smaller as the flow rate increased. As the flow rate increased, the number density increased for the water with the higher initial dissolved oxygen content, and when compared at the same flow rate, the water with the higher oxygen concentration had the higher density. This result suggests that the initial dissolved gas may be responsible for the bubble nucleation.

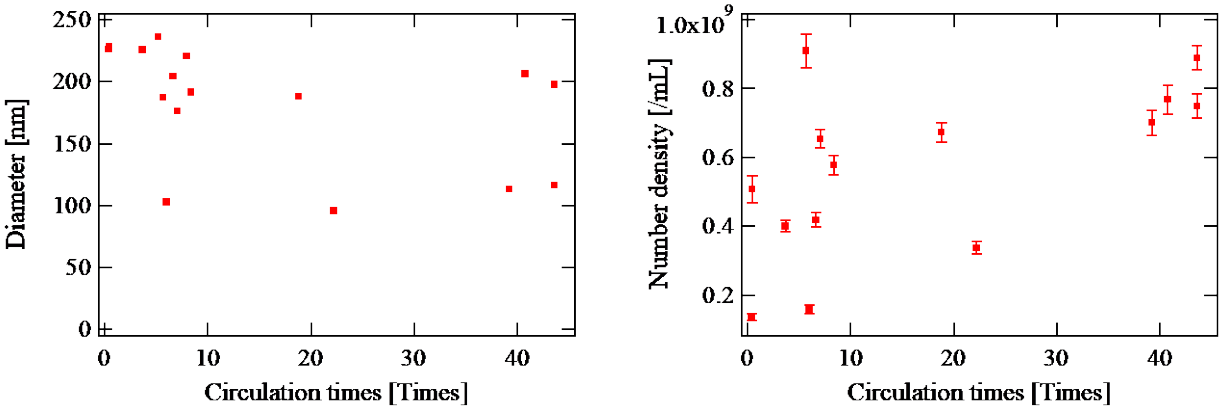


(a) Effect on average bubble diameter (b) Effect on number density

Fig. 4 Effect of initial dissolved oxygen concentration

3.3 Effect of circulation time

The relationship between the time the ultra-purified water circulated through the UFB generator and the number density of UFBs generated is shown in Fig. 5. In this experiment, the Cyclone & Cavitation system generators were used. The experimental results showed that the bubble diameter did not change significantly depending on the number of passages and that the number density trends to be increased with the number of passages.

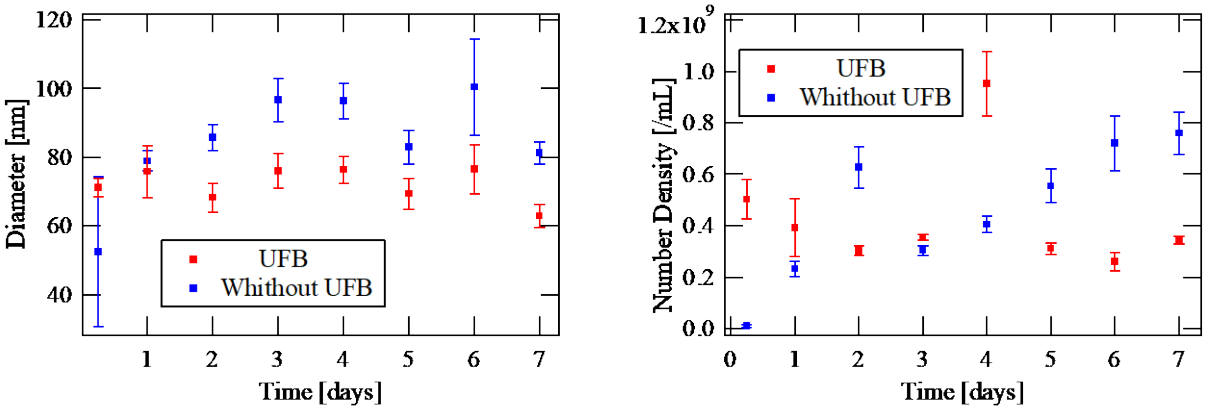


(a) Effect on bubble diameter (b) Effect on number density

Fig. 5 Effect of the number of passage through the UFB generator

3.4 Effect of time after generation

The relationship between the number density of UFBs and the elapsed time is shown in Fig. 6. To investigate the persistence of UFB generated in the Cyclone & Cavitation system generator using ultra-purified water with a flow rate of 7.5 L/min, circulation time of 20 min, water temperature of 20°C, and dissolved oxygen of 6.3 mg/L. Water containing UFB was placed in a 100-mL container, and at the same time, 1 mL of sodium hypochlorite was added and diluted to prevent the growth of bacteria in the container. The number density and bubble diameter were measured immediately after UFB generation (10 min) and every 24 hours for a week. After that, the samples were stored in a sealed container to prevent the influence of air, and kept in a refrigerator (6-7 °C) except when measuring to prevent the growth of bacteria in the container. Ultra-purified water without UFB generation was prepared and measured under the same conditions. In the [Without UFB] bottle, the bubble diameter increased and the number density increased with time. In the [UFB] bottle, the bubble diameter and number density were approximately the same regardless of time. These results indicate that UFB remained at least until 7 days after storage in an airtight container, without significant changes in bubble diameter and number density.



(a) Effect on bubble diameter (b) Effect on number density

Fig. 6 Effect of time dependence

4. Summary

- At the same flow rate, the swirling liquid flow + cavitation type generated a higher density of UFBs than the static mixer type.
- The number density increased with increasing flow rate.
- The higher the initial dissolved gas volume, the higher the density of UFBs generated.
- The number density increased with the number of passes through the generator.
- UFBs remained without significant changes in bubble diameter and number density until at least 7 days later.

References

1) K. Terasaka, S. Himuro, K. Ando, T. Hata, Intriduction to Fine Bubble Science and Technology, Nikkann kougyo shinbunnsya, (2016), pp186-192