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KEYNOTE

Application of new water technology to space travel

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Abstract. Water is a unique chemical substance abundant on the earth. However, its chemical property is not completely understood, e.g., its true freezing temperature is known to be much lower than zero degree Celsius, which is widely seen in atmospheric phenomena. In human body, 60% is water by weight, but most of chemical reactions for life happens in cellular, aquatic environment. Combination of gas with water yields strange phenomena also. These days, 'micro bubble water' is used for cleaning surfaces in factories. What if we generate smaller size bubbles? They tend to stay in the water bottle for more than 6 months. When we choose ozone as gas part, it exhibits potent anti-microbial power. We are exploring applications of 'nanobubble' water for astronaut drinking water sanitation, etc. JAXA plans a program to measure microgravity effect in nano-bubble water shelf life. We may find nanobubble water generators on the spacecraft traveling to Mars.

1. Introduction

Water is a difficult, thus interesting, material to study. Its unique behavior stems from water molecule's hydrogen bond functions. In atmospheric phenomena, which involves development of higher altitude clouds, super cooled water droplets are norm rather than exception. Material scientists are actively looking into chemical functions of water [1]. These days many research fields have developed techniques to record reactions in nanometer scale [2, 3]. Plasma phenomena in water are investigated with these techniques [4].

Now, let's consider bubbles in water. Microbubbles, which typically lasts 15 minutes after generation, are popular as cleaner agent and for other purposes in industry. Its lifetime is short due to larger internal pressure of smaller bubble radius. There are even microbubble generators at some spa facilities. You can easily tell its existence as the look of the water changes from transparent to milky, then transparent again.

Classic Laplace pressure **eq. (1)** tells us that smaller the bubble, shorter the lifetime due to larger internal pressure.

$$p_{in} = p_{out} + \frac{2\gamma}{r} \tag{1}$$

Where p_{in} is the internal pressure of a bubble; p_{out} that of outside; γ the interfacial tension; r radius of a bubble. Due to this pressure difference, smaller the bubble, shorter the lifetime. If smaller bubbles last longer than larger ones, either **eq.(1)** is not applicable or we are dealing with an unknown mechanism.

2. Nanobubbles

2.1 Stability of nanobubble water has been questioned

The definition of 'nanobubble' has not been standardized yet. Standard of small bubble size definition is currently discussed at ISO/TC281. Here 'nanobubble' size is referred to as a diameter less than 1,000 nm. Also, 'nanobubble water' is used synonymously as 'bulk nanobubbles' [5]. Size of 'microbubble' referred to here is around 10 to 100 μm.

If stable nanobubbles stay in water, it is not only against the principle of **eq.(1)**, but also against another classic theory of Epstein and Plesset [6], which takes gas saturation of solution into account. Naturally, there have been many skeptic views against stability of nanobubble water. In 1970's blood stream bubbles (or nuclei) smaller than 100 nm were not observed, thus were not discussed much. Recent developments in verifying nanobubble stability is described below.

2.2 Developments of nanobubble water technology in Japan

There are a number of reports on analysis of nanobubbles, but it is rare to see papers about how to generate bulk nanobubbles. An early report of stable nano- and microbubble was about bubbles naturally generated in sea water [7].

In 2003, Chiba had a device to generate smaller bubbles out of his microbubble water [8]. At 2004 Diving Physiology, Technology & Aerospace Medicine symposium at Tokyo Medical and Dental University, nanobubble water sample was presented. A physiological effect demonstrated at 2005 Nagoya/Aichi World Exposition was that nanobubble water could keep fresh and sea fish in a same water tank for 6 months [9].

Earlier gases used to generate nanobubble water were oxygen and ozone, and water similar to saline. Ozone nanobubble water presented potent bacteriocidal power in vitro and in vivo. It can even sterilize inside of rectum before incision [10]. Other findings include benefits in tissue preservation [11], improvement in clinical periodontitis [12, 13], etc.[9]

The author verified in-vitro bacteriocidal property of Chiba's ozone nanobubble water [14]. The water products are available in quantity through a vender, and ozone nanobubble water (NBW3) is experimentally used for clinical treatments that include irrigation of chronic myelitis, diabetic foot [15]. It is used in seafood industry also.

However, NBW3 generation starts from a natural water source, which means it does not come with an ingredients list. For precision applications, nanobubble generation should start with pure water and known amount of salts. NBW3 presents permanganate-like purple-red color. When it is stored for several months, its purple-red color fades. It may approximately show nanobubble potency.

Ohdaira approached nanobubble generation from a different approach. He demonstrated that dense nanobubble follows water agitation by a polymer propeller [16]. He also claims that electric charge of nanobubbles can be controlled by selecting materials.

2.3 Measuring bulk nanobubbles

Stability and quantification of nanobubbles were studied separately for surface nanobubbles and bulk nanobubbles (nanobubble water) [5]. For theories that supports nanobubble stability in water, as there is no definite explanation yet, Yasui lists 8 models, in addition to his partial hydrophobic cover proposal [17].

There are a number of observations which supports existence of stable nanobubbles in water. As a definitive measurement, independent assessment by microresonator [18] is awaited [5, 19].

There are commercial nanobubble products, but nearly all comes with no specification sheet, and

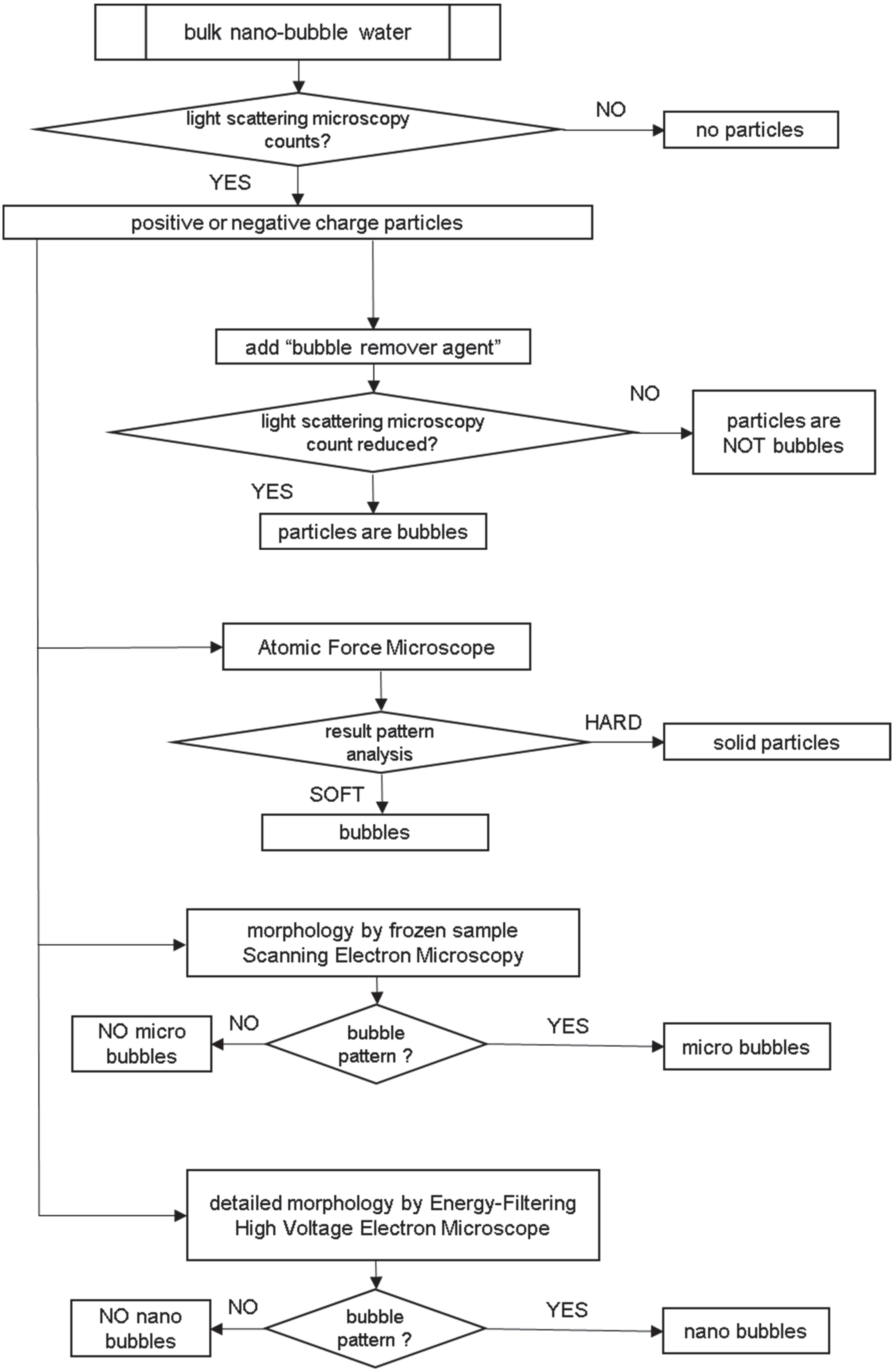

Fig. 1. Nanobubble water qualification flow chart by Ohdaira [10, 16]

their quality is questioned [5]. Ohdaira [10, 16] proposes a 3-tier quality-control system to evaluate and quantify nanobubble water sample (**Fig. 1**).

3. Applying nanobubble water technology for human space flight

Current International Space Station (ISS) uses water launched from ground. Water aboard ISS is used for drinking, added to freeze-dried food, hygiene, air conditioning, spacesuit coolant, source for oxygen by electrolysis, and animal habitat. Air conditioner condensed water and urine are recycled. Due to these ways of usage, reuse of water containers are necessary. NASA segment of ISS uses iodine as bacteriocide, Russian segment use silver. Iodine has to be removed from drinking water. Silver deposits onto piping metal, reducing its effective concentration. Thus, low-ion nanobubble water, ozone or oxygen, is a good candidate for ISS water; we can retain it in drinking water [20]. General water lines can be kept microbe-free, too.

JAXA(Japan space exploration agency), has a program to investigate nanobubble water for life support systems. Sample launch and recovery of microbubble water to see its change in microgravity and space radiation is in its view.

4. Decompression sickness research

When human body is subjected to rapid decrease in ambient pressure, inert gas bubbles form in blood stream and tissues. They cause direct blockage of blood stream, and initiates blood coagulation reaction, leading to tissue ischemia. Extra Vehicular Activities spacesuit has a lower internal pressure, which has a risk of Decompression Sickness.

It was hypothesized that small 'nuclei' are the source of bubble generation. Crevice was thought to play a role [21]. These years, 'microparticle' was found to be in blood stream of humans. Microparticles are thought to be related to platelets. However, developments in nanobubble research field may open new insights into this field [22]. Other effects on animals are also actively investigated [23].

Nanobubble water's application as ultrasound test contrast agent is in research [24]. In diving medicine, manually shaking a small plastic syringe with saline was a standard method to produce contrast medium liquid for diagnosis of Patent Foramen Ovale echocardiogram. The transparent saline begins to present milky look after shaking for a minute. That should have contained nanobubbles together with microbubbles which were the purpose of shaking, as the procedure let water violently rubbed against syringe plastic material.

5. Conclusion

Nanobubble water is actively investigated in material and medical field. Existence of stable nanobubbles in water had been in question, but now we have new evidence. Nanobubble's application field, which includes human spaceflight, is becoming remarkably wider.

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