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将来の有人宇宙探査を見据えた水再生技術

Water Recovery Technology for Future Space Exploration

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1. Introduction

Extraterrestrial outer space is very attractive to humankind, and space exploration programs are being promoted in each country[1)]. Astronaut in space exploration must be reliably supported by robust system. Therefore, Environmental Control and Life Support Systems (ECLSS) are inseparable for human space exploration[2)]. Human activities in the enclosed environment in space require intentionally maintaining a constant oxygen concentration and artificially keeping the concentration of carbon dioxide and trace pollutants at a level suitable for humans. Furthermore, the water supply, which is essential for human life, is also important. Moreover, recycling materials once transported is desirable in space, which leads to a significant reduction in transportation costs. Therefore, on the International Space Station (ISS), urine, sweat, and exhalation, which are water generated by metabolism of astronaut, are processed by the water recovery system to effectively utilize water resources on orbit[3), 4)]. There, regenerated water is used as drinking water and domestic water. Japan Aerospace Exploration Agency (JAXA) is working diligently on research and development to establish an updated water recovery system that is smaller, lighter, and consumes less power than the conventional one. This paper describes the features of JAXA’s water recovery system.

2. JAXA’s water recovery system

The water recovery system is the general term for both urine regeneration system and condensate regeneration system. This section will explain each system separately.

2.1. Urine regeneration system

This system purifies and regenerates crew urine to the drinking water which meets the requirements defined in the system specification for the ISS (SSP41000) and/or the spacecraft water exposure guidelines (SWEGs, JSC63414). The schematic of urine treatment process is shown in **Figure. 1**. The urine regeneration system consists of three major processes: (1) Removal of scale components and resin regeneration, (2) Decomposition of organic carbon, and (3) Removal of inorganic ions. Each process is described in detail below.

(1) Removal of scale components and resin regeneration

At the first stage, magnesium ions and calcium ions, which are scale components, are removed by an ion exchange resin to prevent problems caused by scale precipitation such as clogging of pipes and pumps[5)]. Ion exchange resins remove the target ions by adsorbing them, but if many ions are adsorbed, the resin will eventually become saturated and need to be replaced. The greatest feature of ion exchange resins is that they can be exchanged once to release the captured ions and then returned to the ions before the exchange. This is called revitalization, and it allows the ion exchange resin to be used repeatedly once it has been used. The acid solution and the alkaline solution obtained in the subsequent electrodialysis process are alternately flowed through an ion exchange resin for the revitalization.

(2) Decomposition of organic carbon

Human urine includes the Total Organic Carbon (TOC) about 6000 mg/L. To make drinking water, it is necessary to decompose organic carbon to the TOC level of 3 mg/L or less. We employ the electrolysis for the decomposition of organic carbon. The electrolysis promotes oxidation in a state close to subcritical condition at the high pressure (5 MPa) and temperature (250 ℃), and efficiently decomposes organic carbon. Carbon dioxide and hydrogen generated in the electrolysis process are separated by a gas-liquid separator installed downstream of the electrolysis cell. Here, the behavior of bubbles generated on the electrode surface is expected to be different from that on the ground. Buoyancy is extremely low in a microgravity environment and bubbles may not detach from the electrode surface quickly, resulting in low processing efficiency. Therefore, it is important to evaluate the impact of bubble behaviors in a microgravity environment on the treatment performance of the system by an on-orbit demonstration.

(3) Removal of inorganic ions

Inorganic ions such as Cl^-, Na^+, H^+, and OH^- remaining in water are removed by electrodialysis. The released ions are separated into cations and anions to form acid and alkaline solutions, which are used to revitalize the ion exchange resins as described before.

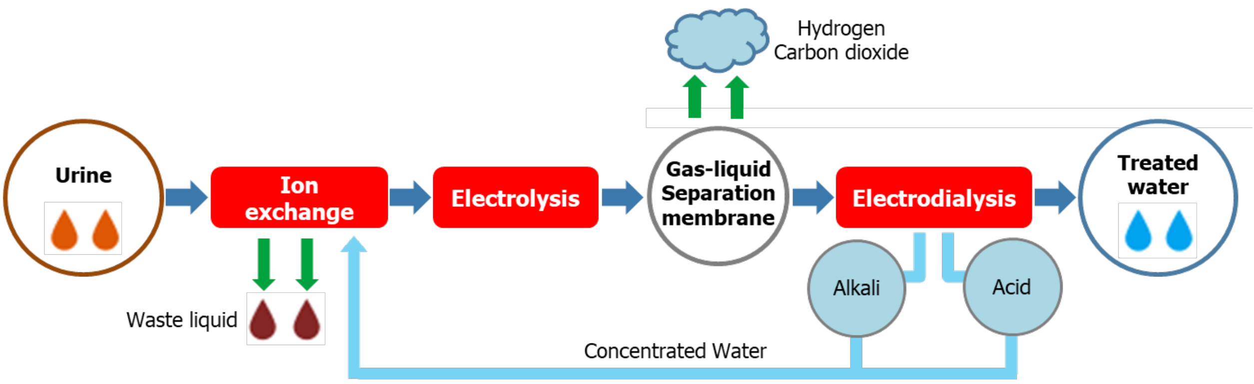


Figure 1 Concept for urine treatment flow of JAXA's water recovery system.

2.2. Condensate regeneration system

This system regenerates condensate to the drinking water. Condensate is liquefied water vapor mainly from the sweat and breath of astronaut metabolism. It can be obtained at air conditioning heat exchanger in a cabin. Compared to urine, condensate is less polluted and contains less organic carbon (about 180 mg/L), so the treatment load is lighter. The schematic of condensate regeneration process is shown in **Figure. 2**. The condensate regeneration system is aimed to be installed in the International Habitat (I-HAB) in the Gateway, the planned space station in lunar orbit. The condensate regeneration system under study consists of two major processes: (1) Oxidization, (2) Ion adjustment. And Sterilization and microbial monitoring would be necessary to add in the system for providing safe water. Each process is described in detail below.

(1) Oxidative decomposition treatment

The Ultraviolet (UV) oxidation lowers the organic carbon in the condensate water. Here, UV lamps are employed for the oxidation. UV lamps oxidize organic carbon, and carbon dioxide gas generated by the oxidation is exhausted through a liquid-gas separator. The TOC level of the treated water should be less than 3 mg/L in the end of this process.

(2) Ion adjustment

Ion exchange reduces remaining ions after the oxidization process. Ammonium NH_4^+ is removed by a cation exchange resin, and Si and NH_3 are removed by an anion exchange resin.

(3) Sterilization and microbial monitoring

The water quality requirements specified for Gateway set the microbiological limits for potable water. Although the condensate water is sterilized with UV light in the oxidization process, bacteria that cannot be fully sterilized may multiply inside the system. Therefore, silver ions or iodine is considered to be used for sterilization to inhibit the growth of bacteria. In addition to this, the installation of a biological monitor in the line is being studied to monitor the number of microorganisms in real time.

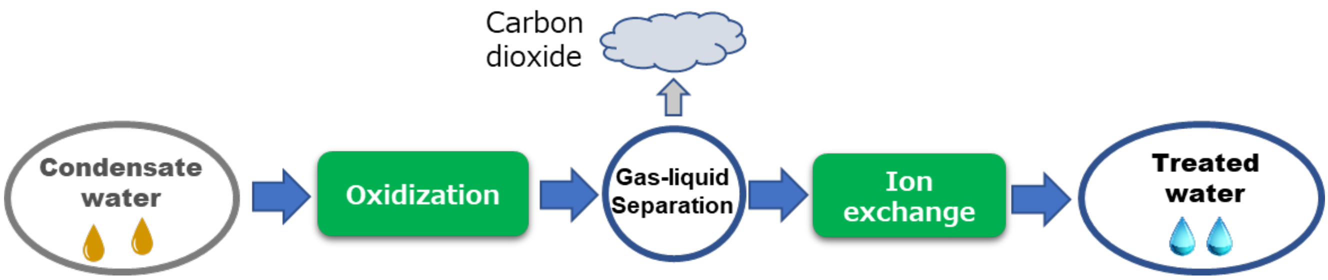
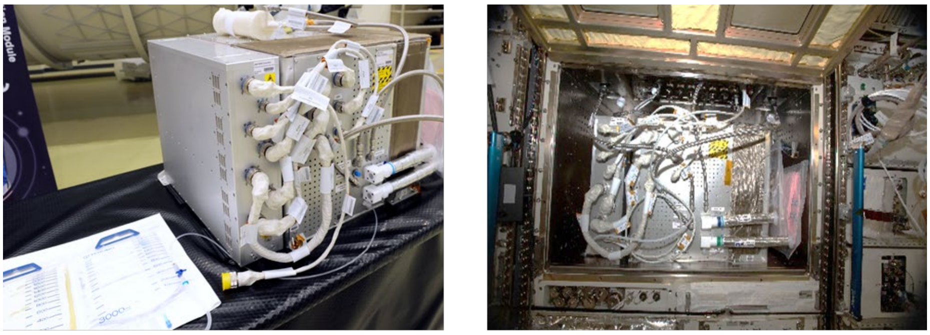


Figure 2 Concept for condensate water treatment flow of JAXA's water recovery system.

3. Future work

An on-orbit demonstration of the urine regeneration system using a sub-scale model for 1 L urine treatment is currently being conducted in the Japanese Experiment Module (JEM) called "Kibo" of the ISS (see **Figure. 3**) [6)]. The objective of the on-orbit demonstration is to check whether the treated water from the simulant urine and the crew's actual urine can meet the required water quality. Here it is also important to evaluate the effect of the behavior of bubbles which generated on the electrode surface in a microgravity environment on the efficiency of the process. The obtained results will be reflected in the design of the system for full scale in future.

In addition, a long-term demonstration of the condensate regeneration system is being conducted using a breadboard model on the ground. The obtained results will be used to design the condensate regeneration system for Gateway.



(i) (ii)

Figure 3 Technological demonstration apparatus of urine recovery system in the ISS: (i) appearance, (ii) on-orbit configuration installed in Multipurpose Small Payload Rack in Kibo[6].

References

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