JASMAC
Conference of the Japan Society of Microgravity Application

OS2-2

将来有人宇宙活動に向けた ECLSS 研究～空気・水再生～

Status of JAXA's ECLSS Development for Future Human Space Exploration Missions

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1. Introduction

Environmental Control and Life Support Systems (ECLSS) will be necessary for human exploration of the Moon, Mars, and other planets. JAXA's R&D Department is developing a regenerative ECLSS to reduce the mass of H_2O, O_2, and other consumables that need to be carried and to improve system reliability. This system has three parts: an air revitalization system, a water recovery system, and a waste management system (Figure 1). One challenge facing ECLSS R&D is to keep the system compact and lightweight while still accommodating large fluctuations in the amount of CO_2 and H_2O vapor produced by human metabolism during work, exercise, and sleep. Another important consideration is that the system must operate normally in the microgravity environment in space. This paper describes the R&D status of the air and water subsystems of the JAXA regenerative ECLSS.

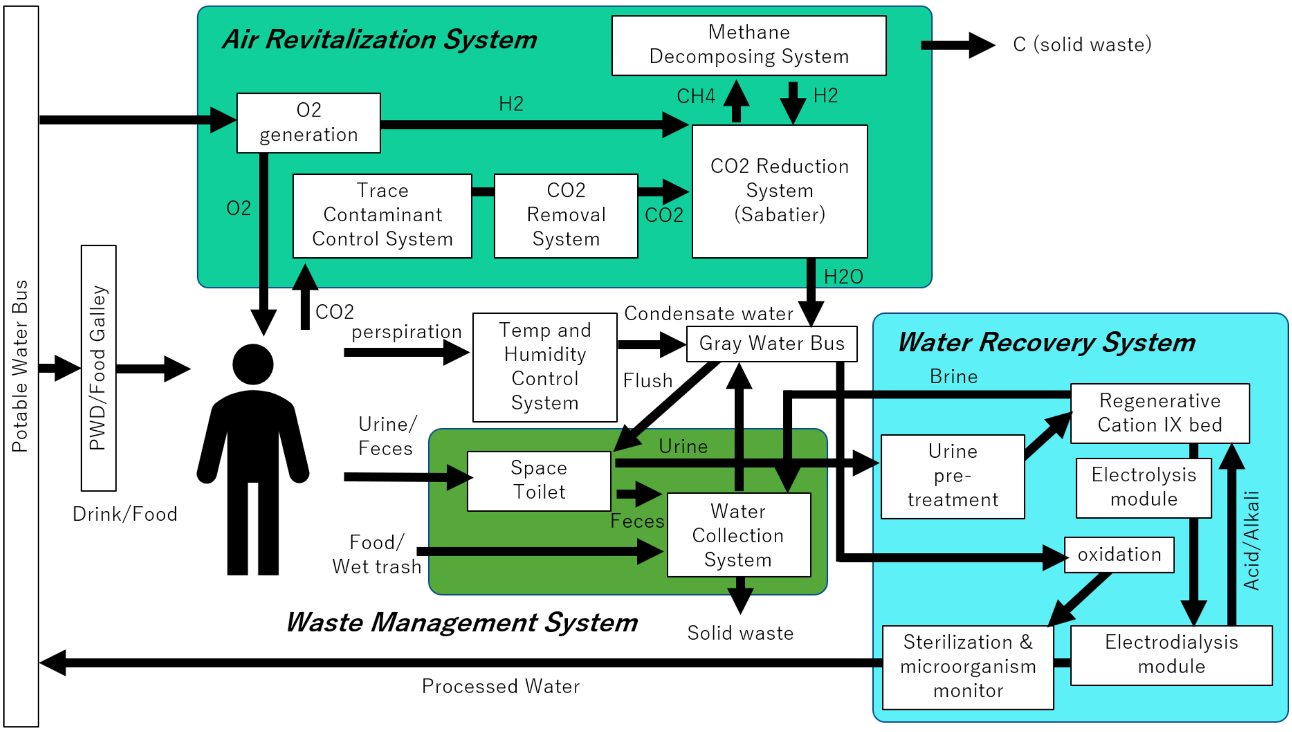

Fig 1. Functional diagram of JAXA ECLSS

2. Air Revitalization System

JAXA's air revitalization system consists of five components. These are the Trace Contaminant Control System (TCCS), the Carbon Dioxide Removal System (CDRS), the CO_2 reduction system (Sabatier system), the O_2 generation system, and the CH_4 decomposition system. The TCCS first removes the contaminants produced by the crew, and the CDRS concentrates CO_2 to about 95%. The concentrated CO_2 is sent to the Sabatier system, which converts the CO_2 into CH_4 and H_2O through the Sabatier catalytic reaction. The water collected in the Sabatier system is sent to the gray water bus for additional cleanup and then to the O_2 generation system, where O_2 is produced by electrolysis. Further information on each component is given below.

TCCS: In the ISS, we have been using commercial grade activated carbon to adsorb trace contaminant gases, but the JAXA system will use porous activated carbon and an oxidation catalyst. The porous activated carbon has high adsorption and aids in reducing the mass of consumables that need to be boarded.

CDRS: In the ISS, NASA uses zeolite as a CO_2 adsorbent, with a high desorption temperature of 350 °C. However, various problems have been reported. JAXA's system uses an amine-based adsorbent with a desorption temperature of 60 °C, making it possible to save energy. This adsorbent adsorbs not only CO_2 but also H_2O vapor, which reduces the absorption capacity of this adsorbent. To avoid this problem, we are developing a four-cylinder system that incorporates a cabin air dehumidification cylinder at the system's front end. This system will be provided to the cislunar station Gateway. To date, the system has successfully absorbed and desorbed CO_2 for four crew members and is currently undergoing long-term performance tests on a ground-based demonstrator[1)]. Future demonstrations are planned on the ISS to improve the TRL to 5. We are also conducting a conceptual study of a two-cylinder system that simultaneously both absorbs CO_2 and dehumidifies air to improve the above system. We will conduct elemental tests in the future.

Sabatier System: This system converts concentrated CO_2 desorbed by the CDRS and H_2 supplied from the O_2 generation system into H_2O and CH_4 by catalysis. One problem is that the system cannot perform the reaction at the ideal stoichiometric ratio because the gas flow rate supplied by the peripheral systems fluctuates. In addition, the system must be designed to minimize power consumption. Thus, the design of the reactor needs to satisfy these constraints. For this reason, we studied the optimum configuration of waste heat utilization of the Sabatier reactor using a nickel-zirconia catalyst[2)]. A shell-and-tube structure was adopted to simulate a general heat exchanger to extend the cooling effect of the reactor. Our new reactor design has low power consumption but maintains reaction efficiency. Also, commercial nickel-zirconia catalyst was used this year, but the applicability of a Sabatier reactor with a ruthenium catalyst (Ru/TiO2) developed by JAXA will also be investigated[3)].

Oxygen Generation System: A cathode-feed water electrolysis system utilizing a polymer electrolyte membrane is being investigated[4)]. The system can produce 2 NL/min of O_2 from water and manage changes in oxygen requirements due to changes in the crews' metabolism. Last year, we confirmed that the system produces enough oxygen for four crew members and can be operated continuously for 1000 hours[2)]. However, the following issues have been identified: confirmation of the lifetime of the system after long-term operation, maintenance of the water quality, and improvement of the gas-liquid separator and the H_2 sensor in the O_2 flow. Currently, long-term evaluations are being conducted to achieve 3000 hours of continuous operation.

Methane decomposition system: This system breaks down the CH_4 produced by the Sabatier reaction into C and H_2, essential to the closed system's hydrogen/mass balance. JAXA has focused on direct CH_4 reforming reactions that do not produce CO_2 during the reaction and has conducted basic research along that.

3. Water Recovery System

The purpose of the water recovery system is to recycle water from crew members' urine, sweat, and food waste into potable water [5)]. This system consists of five components: regenerative ion-exchange resin, an electrolysis unit, an electrodialysis unit, biocide, and a microbial monitor. It is a complex system that aims for a high regeneration rate, low power consumption, and no need for consumables. The features and development status of each subsystem are introduced below.

Regenerative ion-exchange resin: Removes Mg and Ca from urine, which can cause water stains; removing them at this stage prevents clogging of pipes and filters.

Electrolysis system: After the ion exchange, the organic component in the water is decomposed by electrolysis. By electrolyzing water at high temperature and under high pressure, oxidative decomposition lowers the concentration of Total Organic Carbon to less than 3 ppm. Deaeration membranes separate the generated CO_2, H_2, and CO_2. In a microgravity environment, bubbles generated in the liquid do not head for the water surface but remain in the liquid indefinitely. In addition, bubbles attached to the electrode surface may stay due to surface tension, and there is a concern that this could decrease the decomposition efficiency. Therefore, an on-orbit demonstration is now underway to determine how such bubbles affect the processing efficiency.

Electro dialyzer: An ion-exchange membrane removes ions remaining from the previous process, producing water suitable for drinking. The concentrated acid and alkali solutions produced as byproducts of electrodialysis are used to regenerate the ion-exchange resin. In this way, we aim to effectively use acid and alkali resources and create a maintenance-free system.

Biocide: Currently, the ISS drinking water system is facing the problem of controlling biofilm in the pipes, and a biocide with stable disinfection capability is required. In the ECLSS international standardization discussion on future exploration, Ag ions or I has been proposed, and JAXA has been investigating the disinfection performance of these biocides. We have conducted stability and disinfection performance tests of Ag ions and found that the richer the ionic component of the water, the more it affects the stability of the ions. Also, we found that different types of microorganisms have different sensitivities to Ag ions. In the future, we will also conduct bactericidal performance tests using I as a biocide. We plan to reflect these results in our system design.

Microbial monitoring: It has been reported that human immune systems may weaken in space, and the need to pay extra attention to microbial contamination is recognized. To measure the number of microorganisms in the drinking water against the microbial standard values of SSP41000, it is necessary to conduct a culture test using the conventional method of plate agar medium. However, this is unsuitable for routine testing in space because it takes several days to incubate a culture. Therefore, JAXA is studying the applicability of a microbial monitoring method to manage the risk of microbial contamination in water by real-time bioparticle measurement to our ECLS system.

4. Conclusion

This paper outlines the characteristics and development status of the air and water regeneration systems of the regenerative ECLSS being researched by JAXA. By steadily acquiring these technologies, we will provide these systems for future exploration missions such as Gateway, lunar bases, lunar rovers, and Mars systems, and so on.

References

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