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微小重力環境における空気再生システムの現状と課題

Status and Challenges of ECLSS Air Revitalization System in a Microgravity Environment

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Abstract: This paper discusses the research and development status and future work of cabin air revitalization systems of Environmental Control and Life Support System (ECLSS) employed for manned space missions including low Earth orbit. As manned space development is expected to grow, international contributions through the provision of ECLSS will be important in order to increase Japan's presence. To achieve this, the following issues have been identified: continuing research to introduce noval technologies and enhanceing technology readiness level, acquiring and accumulating fundamental data for ECLSS design, establishing an environment for system integration test, and training engineers.

Keywords: Gas-liquid separation, Metabolic mass balance, Front-loading, Human-in-the-loop

1. Introduction

As the post-International Space Station (ISS) after 2030, private companies are considering providing various services utilizing new commercial space stations to be launched in low Earth orbit (LEO). Beyond LEO, as the Artemis program progresses, the Moon surface may become a habitat for humanity in the future, generating new economic and social activities and developing into an economic sphere. In addition, within an international framework, efforts are underway to realize the manned planetary exploration to Mars.

To produce valuable scientific and economic results in manned activities in LEO, on the Moon or on Mars, an Environmental Control and Life Support System (ECLSS) is essential to provide a sustainable environment so that people can live safely and comfortably. This technology is important for ensuring independence and flexibility in manned space activities, and there is an urgent need to establish technology that achieves high efficiency, high reliability, and low cost.

This paper describes the status and challenges of JAXA's research and development on ECLSS air regeneration system.

2. ECLSS Classification and Air Revitalization System (ARS)

ECLSS are classified into "Expendable," "Regenerable," and "Self-sustainable" types according to the scale of the mission and the degree of dependency on the Earth as shown in Figure 1, and the architecture is determined by trading-off risk and cost performance for the mission period, number of crew, system volume, mass, function, performance, safety, and reliability, etc. Indices such as ESM (Equivalent System Mass) and exergy are used as one of the evaluation methods.

An expendable ECLSS is applied for suborbital or low Earth orbit missions. For missions such as manned exploration on the surface of Mars, where logistics from Earth will take more than six months, a regenerable ECLSS is applied utilizing in-situ resources. The larger the mission scale, the more complex the system becomes, making it more difficult to ensure safety and reliability.

An ARS schematic is shown in Figure 2. In this paper, CO_2 removal, trace contaminant control, pressure control, temperature and humidity control are defined as "core ECLSS" technologies, and O_2 production, CO_2 reduction, condensed water reclamation are defined as "regenerative ECLSS" technologies.

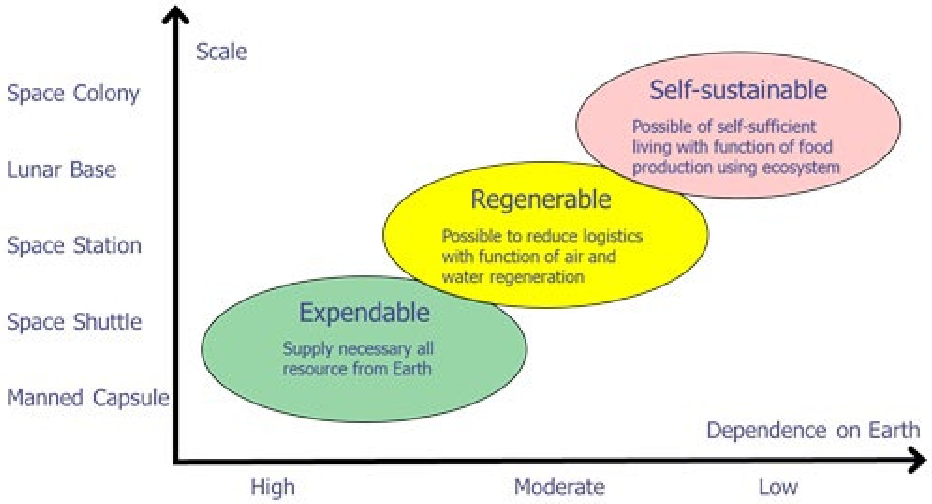

Figure 1. ECLSS classification

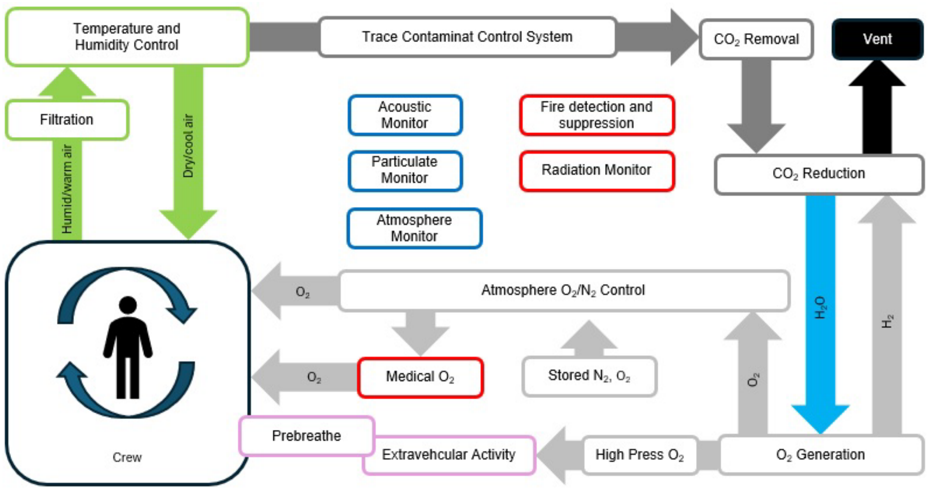

Figure 2. Example of air revitalization system (ARS).

3. Research and Development Status of ARS

The air conditioning system (temperature and humidity control, air circulation) and urine purification unit as one of water recovery system has been operating or demonstrated on the JEM (Japanese Experiment Module) are the only flight items of ECLSS in Japan. Although behind the United States (US) and Russia (RU) related to ECLSS, JAXA has been developing the Demonstration of Removing Carbon dioxide System (DRCS) to be launched on the ISS in the fall of 2025, the Carbon Dioxide Removal System (CDRS) and Trace Contaminant Control System (TCCS) for the Gateway I-HAB, as well as core ECLSS technologies for the Artemis program's lunar pressurized rover.

Even the ECLSS provided by US and RU frequently malfunctions on the ISS, and there are many issues such as reduction of the number of spare parts required and the time required for crew maintenance or component replacement, and improvement of crew's quality of life (QOL). To address these challenges, we are promoting research into the architecture of next-generation air regeneration systems capable of maintaining performance even in reducing the system's size and power consumption and improving reliability[1,2]. Some of the elemental technologies and auxiliary devices currently under research are shown in Figure 3.

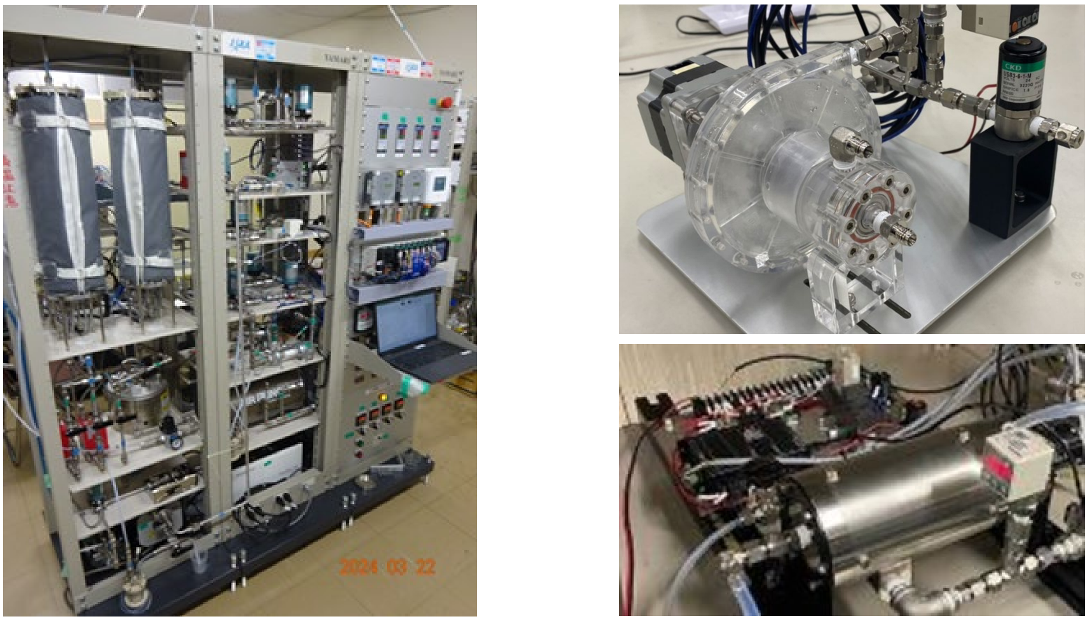

Figure 3. CO_2 removal test apparatus using novel adsorbent (left),
Improved prototype gas-liquid separators (right).

4. Future Work

4.1. Technology Readiness Level (TRL) Enhancement

There are a variety of air regeneration technologies, and it is particularly important to evaluate the applicability of novel or breakthrough technologies that can lead to system improvements and to mature these technologies including auxiliary components. Water vapor is always involved in each element of ARS, and the separation of air and water is a mandatory operation for human spaceflight life support. Otherwise, water condensation will increase the likelihood of failure of ARS components and extend the time required for crew maintenance or component replacement. Therefore, solving the gas-liquid two-phase flow problem under microgravity is still key factor in research and development of ECLSS. It is necessary to archive and create a database of research results so that we can provide the best solution for the determined architecture as down-selected technologies.

4.2. Fundamental Data for ECLSS Design

The specifications required for an ARS are based on the daily mass balance of human metabolism as shown in Figure 4, which is the data obtained from the closed environment test conducted for five Japanese subjects staying at the Isolation Chamber in JAXA Tsukuba Space Center (TKSC) for 48 hours in 1999[3)]. However, because there is very little data available for Japanese people, we are forced to refer to NASA's findings[4)]. Another approach is to estimate O_2 consumption rate and the respiratory quotient from the heat production (energy expenditure) corresponding to crew's daily activity levels[5,6)]. Anyway, it is necessary to accumulate data on the Japanese metabolic mass balance in a microgravity environment for ECLSS design.

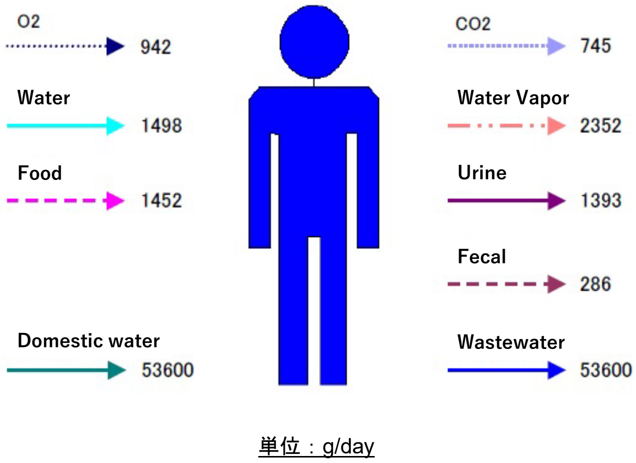

Figure 4. Daily mass balance of 67 kg person.

4.3. Infrastructure for System Integration Test

To increase the probability of mission success, it is important to conduct sufficient technical verification (i.e. front-loading) and ground integration tests including hardware, software, and operations before flight. However, because the current TKSC’s isolation chamber is no longer possible to maintain airtightness, and there are no similar test chambers in Japan, the human flight qualification is granted through "static" testing of the individual devices, which is not always the desired results. There are also some limitations on the use of analog sites overseas. The system being developed should be evaluated through long-term human-in-the-loop ground "dynamic" testing as the most high-fidelity demonstration of integrated ECLSS functionality that could be undertaken before flight, subjected to metabolic loads and environmental changes close to actual space activities. Far more than a life support test, it serves as a crew-equipment interface check and operational training. It will also be useful for accumulating human metabolic data, and for support on-orbit anomaly investigations as needed.

4.4. Human Resource Development

To pass on the ECLSS technology to the next generation, it is important to develop human resources who will be involved in research and development of ECLSS. Since there are no departments specializing in ECLSS in Japan, JAXA staff members have supervised graduate students' educational and research activities using JAXA's ECLSS-related facilities and equipment through the collaborative graduate school education system. There is a platform that promotes education and technology development for ECLSS, refer to as ECLSS LAB comprises a network of students and professionals focusing on building foundational ECLSS knowledge, fostering talent for next-generation technologies, and facilitating collaboration among industry, academia, and government[7]. To achieve further development, it is necessary to improve facilities and environments where students, engineers, and others can conduct research into ECLSS, and to continue and enhance educational activities about the importance of ECLSS in manned space development.

5. Conclusion

Recently, with the participation of start-up companies in space development, space including low Earth orbit has the potential to develop into a new economic sphere, and there is a demand for the development of ECLSS for the mission. To provide an ECLSS air regeneration system suitable for a microgravity environment, we will pursue novel or breakthrough technologies, enhance TRL, and address many challenges, such as setting up the development environment, conducting system integration tests and training engineers involved in research and development, to contribute to the mission success and increase Japan's presence.

References

1) Kazuhiro Toda, Asuka Shima, and Masato Sakurai: Study on Applicability of New Adsorbent CeO_2 to CO_2 Removal Systems Resulting in Decrease of Volume, Weight, and Power Consumption, Proceedings of 54th International Conference on Environmental Systems (2025), ICES-2025-285.
2) Asuka Shima, Yoshitsugu Sone, and Masato Sakurai: Carbon Dioxide Reduction-Oxygen Production Tandem Reactor: Development of the Electrolysis Part and Full-scale Testing, Proceedings of 54th International Conference on Environmental Systems (2025), ICES-2025-164.
3) Kazuhiro Toda, Susumu Baba, and Haruka Hashimoto: Review of Basic Data Obtained through Manned Closed Environment for Design of Regenerative ECLSS, Proceedings of 66th Space Sciences and Technology Conference (2022), 3J03.
4) Michael K. Ewert, Thomas T. Chen, and Camilah D. Powel: Baseline Values and Assumptions Document, REV2, NASA/ TP-2015-218570 (2022).
5) Ergonomics of the thermal environment－Determination of metabolic rate, 3rd ed., ISO 8996 (2021).
6) SASAKI Satoshi, UENISHI Kazuhiro and ISHIDA Hiromi: Dietary Reference Intakes foe Japanese, 2025, Kagawa Nutrition University Publishing Division (2025).
7) Motoharu Kusano, Taisei Hasumi, et.al: ECLSS Lab Platform－Current Activities and Future Plans in the ECLSS Ecosystem in Japan, Proceedings of 54th International Conference on Environmental Systems (2025), ICES-2025-247.