OS2-5

国際学会での発表から見る海外の ECLSS 研究開発状況

Review of overseas ECLSS R&D status from presentations at an international conference

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1. Introduction

Environmental control and life support systems, or ECLSS, have attracted much attention for future long-term human exploration missions. The European Space Agency (ESA) installed a new air revitalization system, the Advanced Closed-Loop System (ACLS), on the International Space Station (ISS) in 2018 to demonstrate the feasibility of the system.[1)] In 2019, the Japan Aerospace Exploration Agency (JAXA) presented a water recovery system on the ISS.[2)] JAXA has also been developing subsystems for CO_2 removal and trace contamination control (TCCS) as parts of its closed-loop air revitalization system (**Fig. 1**) for the upcoming Gateway project.[3)] In the United States, the National Aeronautics and Space Administration (NASA) and the private sector have developed a variety of ECLSS technologies to replace or upgrade current ISS systems.

This paper presents the author’s latest research into ECLSS, especially concerning air revitalization systems, by reviewing presentations from the 50th International Conference on Environmental Systems (ICES) held fully online last July 2021.

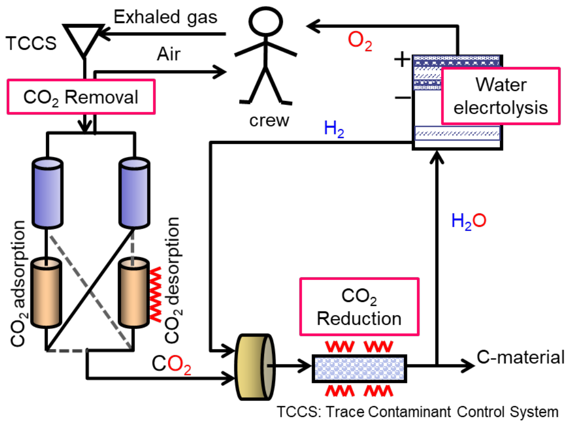

Fig. 1　Schematic of the closed-loop air revitalization system

2. Review of the 50th International Conference on Environmental Systems

2.1 Overview

The ICES focuses on disseminating technical and scientific information on topics related to living and working in space environments. The conference was organized in 1971 by the ICES Steering Committee. Five committees coordinate this annual conference by organizing technical sessions and soliciting technical papers for presentation and publication. The five committees described below consist of groups responsible for organizing topically oriented sessions at the ICES every year:

- ICES Thermal and Environmental Control Systems (TECS) Committee: the main organizer of the 100-series sessions, which are concerned with thermal technology for spacecraft;
- ICES International Committee (IIC): the only committee in which the Program Chair is from Europe and most members are other than American. They organize the 200-series sessions, including bioregeneratable life support, related thermal control technology, and sensor technology;

- American Institute of Chemical Engineers (AIChE) Environmental Systems Committee: this committee organizes the 300-series sessions, in which research and development of component technologies for physicochemical processing of air, water, and waste are featured with local resource utilization;
- American Society of Mechanical Engineers (ASME) Crew Systems Committee: their 400-series sessions feature research on topics related to extravehicular activities; and
- American Institute of Aeronautics and Astronautics Life Science and Systems (AIAA-LS&S) Technical Committee: space architecture and related research such as radiation issues and fire safety are the main topics for their 500-series sessions.

According to the ICES committee, 252 manuscripts were submitted to the 50th ICES, 78 of which were presented on ECLSS during the 300-series sessions.[4) 5)] Session303: "Physico-chemical Life Support –Water Recovery & Management Systems – Technology and Process Development" had the largest number of presentations (23) at the conference this year. There were fifteen presentations on air revitalization systems at the session of ICES302: "Physico-chemical Life Support – Air Revitalization Systems – Technology and Process Development," fewer than the presentations at other recent sessions, as shown in **Fig. 2**. Three of these presentations were made by JAXA. The rest were all presented by NASA or American companies. We have not been able to obtain updated information on the development status of ECLSS in Europe from the conference this year. This paper will introduce the presentations on air revitalization systems at ICES302 and review them.

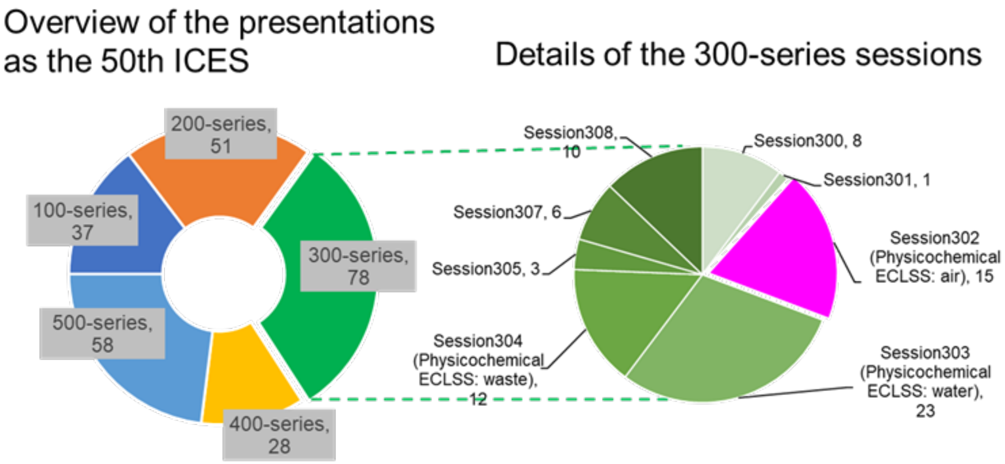

Fig. 2 Breakdown of the number of presentations at the 50th ICES. See Reference 5 for the session details.

2.2 CO_2 Removal

An essential function of an ECLSS system is removing CO_2 from the cabin air. The CDRA, the Carbon Dioxide Removal Assembly, has done this on the ISS since 2001 to maintain the partial pressure of CO_2 in the ISS cabin atmosphere to less than 4 mmHg. However, it is recognized that current ISS CO_2 removal technology has reliability and capability gaps that must be filled for future missions. Specifically, mass, volume, and power must be reduced. The partial pressure of CO_2 needs to be 2 mmHg or less. This year, eight of the fifteen reports were on CO_2 removal.

Knox et al. showed the optimization of the four-bed CO_2 scrubber (4BCO2), the next-generation four-bed molecular sieve (4BMS) system, for flight testing on ISS.[6)] The 4BMS has operated in a partial closed-loop configuration onboard the ISS as CDRA. The 4BCO2 system has been designed based on lessons learned from CDRA[7)] to prove that the remaining concerns about reliability and performance have been mitigated. In that paper, the authors mentioned how much performance had improved by CO_2 sorbent optimization, modifications to the heater fins, and the reduction or replacement of a desiccant bed of zeolite 13X. The same group submitted another paper on 4BCO2 development.[8)] They succeeded in reducing the 4BCO2 bed volume and mass more than 20% below those of CDRA while maintaining CO_2 removal significantly higher than the 4.16 kg/day requirement with inlet air CO_2 partial pressure of 2 torrs. In addition, the 4BCO2 average heater power consumption was only 63% that of CDRA.

Discovering new materials for CO_2 capture has been a popular topic in CO_2 removal. One idea is to use liquid amines. Following the previous presentation,[9] Chu et al. reported developing liquid amine test systems experimentally and in simulations.[10] Ionic liquids are regarded as another possible technology for CO_2 scrubbing. The Honeywell group showed lab-scale integration and testing of their Carbon Dioxide Removal by Ionic Liquid System (CDRILS) to develop a full-scale flight-like prototype.[11] They have reported continuous stability studies on the ionic liquid and membrane contactor, reaching their two-year milestone. Nabity et al. demonstrated modeling for a CO_2 removal system using a supported ionic liquid membrane.[12] They developed a MATLAB/ Simulink® Model of a novel CO_2 system and used it in a Monte Carlo analysis to clarify the influence of design parameters on volume and power. Their demonstration showed that supported membranes might have many advantages over current technologies.

Furthermore, two presentations were on numerical research on a CO_2 removal system called the CO_2 Deposition System (CDep), which utilized deposition by maintaining a cold surface below the CO_2 deposition temperature at spacecraft atmospheric conditions.[13, 14]

A presentation offering a new perspective on CO_2 removal was put forth by Alcid et al.[15] They utilized temperature-swing CO_2 adsorption in a CO_2 compression system. It is reported that the system integration with 4BCO2 is ongoing. Their follow-up paper is expected.

2.3 CO_2 Processing

Although processing CO_2 removed from cabin air with hydrogen provided from an oxygen generator to produce water is a key step in closing the loop of air revitalization, the presentations on catalytic CO_2 hydrogenation were provided by JAXA only.[16, 17] Another way of CO_2 processing, direct electrochemical conversion of CO_2 to oxygen with ethane, was reported by Brown et al.[18] Applying this reaction system would potentially contribute to reducing the complexity of ECLSS O_2 recovery by replacing three future ECLSS subsystems: the current CO_2 reduction assembly to make methane and water; the plasma pyrolysis assembly, which converts CH_4 to H_2 and C; and the oxygen generation assembly.

2.4 O_2 Generation

Except for JAXA,[17] only Takada et al. from NASA presented a paper on O_2 generation.[19] The status of the current Oxygen Generation Assembly (OGA) onboard the ISS was reported, and various technical issues of the OGA were addressed (e.g., failures of the recirculation pump, degradation of the cell stack, and the stability of hydrogen sensors). Based on this information, the authors proposed redesigning and upgrading the OGA, especially for the cell stack, housing, hydrogen sensors, and recirculation loop.

2.5 Others

This year, Honeywell gave presentations on CDRILS and methane pyrolysis.[20] Methane pyrolysis has been developed for allowing close to 100% of the O_2 in exhaled CO_2 to be recovered for reuse. The presentation investigated the effects of surface area, porosity, gas diffusion, loading capacity, and maintenance interval in substrate design to optimize the resulting equivalent system mass.

The investigation on granular activated carbon sorbents for the TCCS onboard ISS was presented by Monje et al.[21] Current TCCS has adopted a commercial product that has become obsolete and is no longer available for purchase or manufacture. Thus, it is essential to identify and characterize suitable alternative sorbents. The effect of particle size of activated carbon sorbents was investigated by measuring adsorptive capacities for ammonia and ethanol.

3. Summary

This paper introduces the R & D on air revitalization for ECLSS presented in the 50th ICES. There are many technical issues and difficulties to overcome in the air revitalization system for long-duration missions. We need to continue researching and developing novel solutions that will resolve those problems.

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