JASMAC
Conference of the Japan Society of Microgravity Application

OS2-3

マイクロ・パーシャルグラビティにおける流体現象とECLSS

Fluid Phenomena in ECLSS under Micro or Partial Gravity Conditions

松本聡 [1], 猿渡英樹 [1]
Satoshi MATSUMOTO[1], Hideki SARUWATARI[1]
1 宇宙航空研究開発機構，Japan Aerospace Exploration Agency

1. Introduction

In our living space on the earth, atmosphere does not have to be actively controlled because the atmosphere becomes a large buffer and the temperature, oxygen, carbon dioxide, and water balance is well established. On the other hand, in human activities in the closed environment of space, it is necessary to intentionally maintain the oxygen concentration and carbon dioxide and trace contaminant concentration suitable for humans by artificial means. The supply of water, which is indispensable for human life, is also important. Furthermore, the recycle of materials once transported is desirable in space, that leads to the significant reduction of transportation costs.

The Environmental Control and Life Support System (ECLSS) is a system hardware with regenerative functions, which maintains the thermal stability of the cabin, provides a pressurized, habitable environment in the crew compartment for the crew, and supplies water and stores crew liquid waste.

The functions of ECLSS are roughly divided into five. (1) Pressure Control System (PCS) pressurizes the cabin with mixture of nitrogen and oxygen with the oxygen concentration suitable for breathing. (2) Active Thermal Control System (ATCS) is to collect waste heat from equipment and crew metabolic and to transfer heat to overboard. (3) Atmospheric Revitalization System (ARS) adjusts the air environment to the appropriate conditions for human activity and regenerates oxygen and water. (4) Water Recovery System (WRS) purifies wastewater which is crew urine and condensate from temperature and humidity controller. (5) Waste Management System (WMS) collects urine and faces, and recycles the crew excrement and waste onboard.

For future human exploration on the Moon and Mars [1)], we are doing research and development on the ECLSS to establish more compact, less power and less consumable than conventional one. Unlike the ground, in future exploration, the gravitational acceleration will differ depending on the place of activity, such as microgravity if it is an orbit, 1/6 G on the moon, and 1/3 G on Mars. In order to maximize the ECLSS performance, it is necessary to design with a firm understanding of gravity dependence on each ECLSS subsystem.

This paper focuses on the gravity dependent phenomena in ECLSS, especially on the electrolysis using in the Water Recovery System.

2. Gravity effect

2.1 Airflow system

Each function in ECLSS should be designed to be insensitive to changes in gravity. This is because the performance that has been fully verified on the ground can be demonstrated in space as it is. In the airflow system such as Trace Contaminant Control System (TCCS) and Carbon Dioxide Removal System (CDRS), the Richardson number, Ri, is one index to describe the ratio of buoyancy and inertia of air flow. Ri is defined as eq. (1)

$$\mathrm{Ri} = \frac{g\beta\Delta TL}{u^2} \quad (1)$$

where, g is the gravitational acceleration, β is the thermal expansion coefficient, ΔT is the temperature difference, L is the characteristic length, u is the velocity. For example, in our carbon dioxide removal system, Ri is estimated to be order of 10^{-3} in the terrestrial gravity condition. This means that buoyancy effect would be ignored even on the earth.

2.2 Electrolysis system

Many subsystems of ECLSS utilize chemical reactions such as adsorption reactions and catalytic reactions, and electrochemical reactions of electrolysis [2-4)]. Electrochemical processes are nanoscale, microscale, and macroscale multi-scale phenomena. Most of the water treatment, fuel cells, batteries, hydrogen production, oxygen production, etc. generate gas at one or both electrodes. These gases form bubbles that play an important role in electrochemistry. Bubbles are generated from the electrodes by the electrolysis of water, and the desorption and transportation of the bubbles from the electrodes affect the electrolysis performance[5)].

The water recovery system is a purification system of wastewater such as urine and condensate, and provides a potable water. In our water recovery system employs the electrolysis with high temperature and high pressure to decompose the organic carbon in urine. The bubbles are produced at electrodes. All electrochemical systems are affected by the adherent layer formed by the generation of bubbles as a result of supersaturation of dissolved bubbles in the bulk. This adherent layer forms an inert region on the electrode surface, preventing the new bulk solution from contacting the electrode surface and causing the required reaction. In addition to this effect on mass transfer, the adhesive layer acts as an electrical shield, reducing conductivity and increasing ohm resistance on the electrode surface. It is important to separate the bubbles adhering to the electrodes. Buoyancy force works on the bubbles under gravity and the flow of the bulk liquid plays a role of pushing away the bubbles and contributes to stable electrolysis. Here, the basic hydrodynamics of bubbles on the electrode surface and the basic hydrodynamics of the interaction of bubbles with a liquid bulk solution is examined.

A model in which a rod electrode with a diameter of 6 mm is installed in the center of a circular tube with an inner diameter of 10 mm, the rod electrode is the anode, and the inner wall of the circular tube is the cathode will be examined. The electrolyte is flowing between the electrodes at a flow rate of 28 mm^3/s. It takes to perform order estimation of fluid behavior between electrodes.

First, the Reynolds number Re, which is the ratio of inertial force to viscosity, is expressed in eq. (2).

$$Re = \frac{uL}{\nu} \quad (2)$$

Where, the characteristic length L is employed as the distance between the electrodes, ν is the kinematic viscosity. The Reynolds number calculates about 80, which means laminar flow.

The weber number We, which is the ratio of inertial force to surface tension as described in eq. (3).

$$We = \frac{\rho L u^2}{\sigma} \quad (3)$$

Where, ρ is the density of liquid, s is the surface tension between liquid and bubble. The weber number estimates to an order of 10^{-3}. The inertial force of the flow is smaller than the surface tension, and the gas-liquid two-phase flow is a phenomenon dominated by the surface tension. There might be almost no deformation of bubbles due to the flow.

The static bond number Bo, which is the ratio of buoyant and surface tension. This is gravity dependent nondimensional number as defined in eq. (4).

$$Bo = \frac{\Delta\rho g {L_B}^2}{\sigma} \quad (4)$$

Where, $\Delta\rho$ is density difference between bulk fluid and bubble, L_B is bubble diameter. Assuming that the bubble diameter is 100 μm, the number of bonds is 0.05 under the gravity on the ground, and it is considered that the surface tension is dominated even on the ground.

3. Concluding remarks

The technological demonstration of the water recovery system for a purification of urine is carrying out in microgravity in Japanese Experiment module "Kibo". It is considered that the influence of gravity on the bubble behavior is small from the hydrodynamic point of view. However, since electrolysis is affected by the temperature distribution and electric field on bubbles, it is necessary to examine these effects as well. Generally, under microgravity, bubbles are not easy to depart from the electrode surface. As a result, it is presumed that the effective area of the electrode is reduced and the conduction path is narrowed, so that the electric resistance value is increased and the current value is decreased, so that electrolysis would be suppressed.

Of cause, electrolysis processes are very complicated[6)]. The characteristics of this layer depend on the interface between the three phases. These are solid, gas, and liquid, electrodes, bubbles, and bulk solutions, respectively. These interfaces are strongly related to electrode shape, cavity, wettability, bubble composition, bulk solution chemistry, flow rate, reaction components (current density, etc.). On the other hand, the separation and release of bubbles from the electrode surface causes wake or micro-convection that facilitates mass transfer at the separation position. A proper understanding of these electrochemical processes is important and is the next challenge.

References

1) Ed. International Space Exploration Coordination Group (ISECG): The Global Exploration Road Map 3rd edition (2018)

2) Y. Sakai, T. Oka, S. Matsumoto and S. Nakanoya: Development status in 2021 of JAXA CO2 removal system for closed ECLSS, 50th International Conference on Environmental Systems, ICES-2021-0037 (2021).

3) C. Yamazaki, S. Futamura, T. Oka, S. Matsumoto, A. Shima, M. Sakurai and S. Nakanoya: Development status of Oxygen Generation System and Sabatier System for future exploration missions, 50th International Conference on Environmental Systems, ICES-2021-0181 (2021).

4) T. Nagase, M. Goto, Y. Sakai, S. Nakanoya, K. Ishiwata and Y. Matsumoto: The Status of JAXA's Water Recovery System, 48th International Conference on Environmental Systems, ICES-2018-0152 (2018).

5) T. Fujimura, W. Hikima, Y. Fukunaka and T. Homma: Analysis of the effect of surface wettability on hydrogen evolution reaction in water electrolysis using micro-patterned electrodes, Electrochemistry Comm., **101** (2019) 43.

6) A. Taqieddin, R. Nazari, L. Rajic and A. Alshawabkeh: Review—Physicochemical hydrodynamics of gas bubbles in two phase electrochemical systems, J. Electrochem Soc., 164 (2017) E448.