Study of Water Electrolysis Under Microgravity Conditions for Oxygen Generation - Applied to a Ground Demonstration System and Development of New Systems -

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The Japan Aerospace Exploration Agency (JAXA) has been studying, and developing the Environmental Control and Life Support System (ECLSS). In particular, an air regeneration system to support long-duration manned space missions beyond Earth's orbit. One of our goals is to develop an air regeneration system that is lightweight, compact, and highly energy efficiency. The air regeneration system is comprised of; a water electrolysis subsystem for oxygen generation[1, 2)], a CO_2 removal subsystem, and a CO_2 reduction subsystem. In this paper, we report on improvements to the water electrolysis subsystem for the oxygen generation system. The water electrolysis cell uses a solid polymer electrolyte (SPE) developed by JAXA, and a water/gas separator to separate generated hydrogen from circulated water using a membrane[3)]. In our previous research, the electrolyzer achieved low hydrogen cross-leakage by improving a catalyst of the membrane electrode assembly (MEA), and the pressure drop of the separator was reduced to approximately one third of that of the previous design. The result led to a safer and more energy efficient oxygen generation system. Therefore, the electrolyzer and the separator technologies were adopted as a ground demonstration model for JAXA's air regeneration system. We also attempted to improve a subsystem including an electrolyzer, a water circulation and water/gas separation function by removing a water circulation and an independent separator. As a result, we succeeded in creating a simple and lightweight subsystem.

1. Nomenclature

CO_2	=	*Carbon dioxide*
CH_4	=	*Methane*
ECLSS	=	*Environmental Control and Life Support System*
H_2	=	*Hydrogen*
H_2O	=	*Water*
ISS	=	*International space station*
JAXA	=	*Japan Aerospace Exploration Agency*
LEO	=	*Low earth orbit*
MEA	=	*Membrane Electrode Assemblies*
SPE	=	*Solid Polymer Electrolyte*
O_2	=	*Oxygen*

I. Introduction

In recent years, the expansion of manned space activities to the moon and Mars are expected. Along with it, an environment control life support system (ECLSS) with high material regeneration rates. Which will be required to be operated on more long term missions. Therefore, it is necessary for technologies to

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make the system small, light weight, and power saving. As has been adopted in ISS, in the current technology, the air regeneration system of figure 1 is a practically superior system. This could be achieved by a recirculating system. A water electrolysis system produces O_2 and H_2 from water. The crew consumes the O_2 and exhales CO_2, which is concentrated in an absorber by a CO_2 removal system using a pressure swing. The concentrated CO_2 is then reduced by a CO_2 reduction system using the

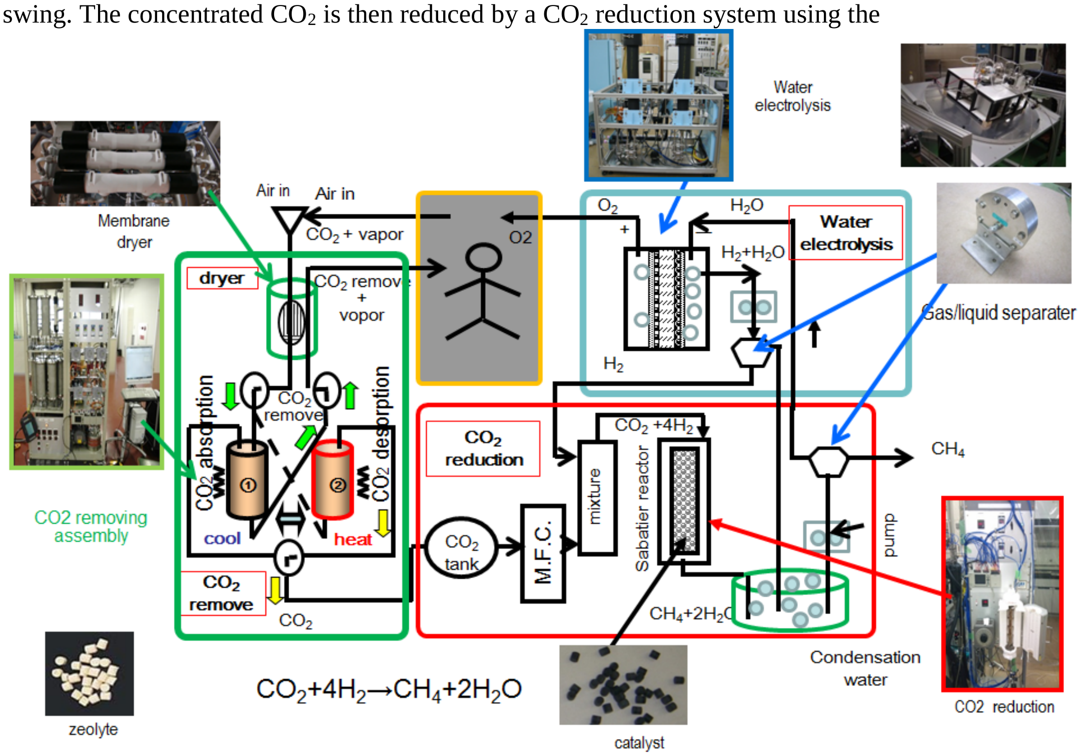


Figure 1 Concept of air revitalization system using CO_2 reduction

Sabatier reaction ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$), producing H_2O and CH_4. The water is then electrolyzed and consumed by the crew again. This proposed air regeneration system can thus significantly reduce the volume of water supply needed, and it's only waste material is CH_4. The supply of crew O_2 on the International Space Station (ISS) is also produced mainly by electrolyzing water [4, 5)]. Producing O_2 by water electrolysis has a much lower cost than supplying O_2 from the ground, so water electrolysis for O_2 generation has been a very important topic of study, in particular by the European Space Agency (ESA)[6, 7)]. It is desirable to further reduce the supply of water required for O_2 generation to enable longer periods of human habitation in low Earth orbit, and missions beyond. The theory of the air regeneration system has been well studied, but systems that operate well enough to be of practical use have not yet been developed. Although, early realization of a closed-cycle air regeneration system for space applications is desirable, there are many technical problems to overcome. One of the main problems is the significant limit on the amount of energy available. The maximum power generating capacity of the ISS is about 120 kW, and the available power on manned missions beyond Earth orbit will typically be more constrained. At least 0.75 kW is theoretically required to generate sufficient O_2 for ten crew members by water electrolysis, most of which is required for controlling systems, and consumed by various energy losses. Another problem is that water/gas separation is required in many parts of the air regeneration system, but it is difficult to design a system that operates well in microgravity. This problem is particularly acute in the water electrolysis system, because the water required for electrolysis and the generated gas are constantly in contact, and incomplete water/gas separation not only has adverse effects on downstream sub-systems, but also leads to the waste gas having a high H_2O content.

We have prioritized low energy consumption and safety of the oxygen generation water electrolysis system by concentrating on improving the electrolysis cell, and the water/gas separator. Previously, water electrolysis at a very low cell voltage was achieved by an electrolysis cell using a solid polymer membrane developed by JAXA. A cross leak of the cell is also very small, and it is very safe compared to the previous electrolytic cell. Furthermore, energy efficient water/gas separation was achieved by using the membrane separation system with no moving parts, and the separator was demonstrated to operate at any gravitational direction. We have also succeeded in decreasing the low pressure drop of the separator[10]. Now, we've made a 10 cell electrolyzer and a 4 stack water/gas separator using these research results as an application of our basic research. Then, the electrolyzer and the separator are mounted in the ground demonstration model of air regeneration system's oxygen generation system (being proceeded by JAXA). In tests using the model, we will evaluate the basic properties and long-term operation characteristics of the electrolyzer, and the separator. Then compare them to the previous model. In addition, we hope that findings on the impact of the CO_2 reduction device which is downstream of the oxygen generation system is obtained, and easily introduced to the installation of the ground demonstration model in section 2.

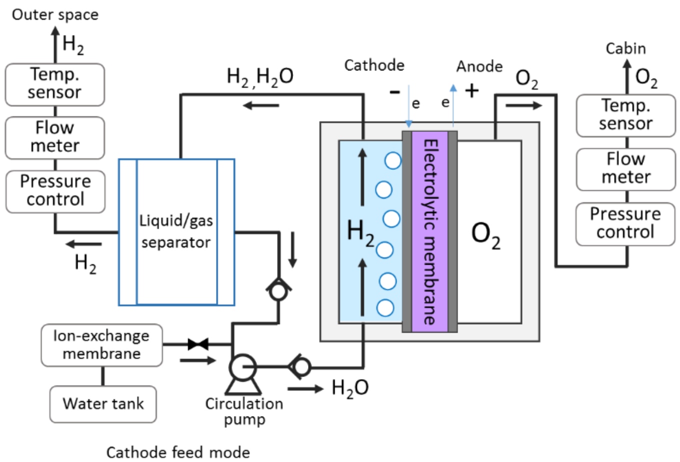


Figure 2 Previous system using water circulation.

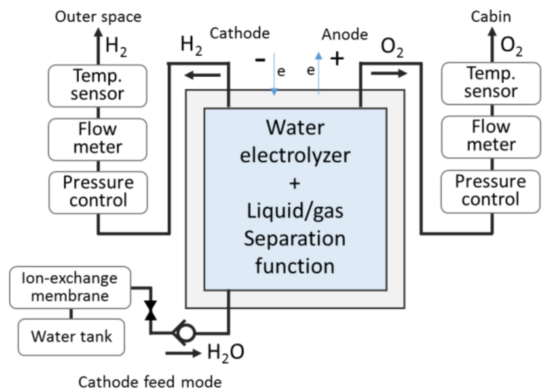


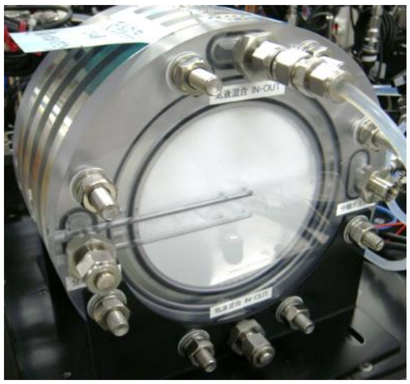
Figure 3 Improved system that is using electrolysis unit which has water/gas separation function and is not required water circulation.

On the other hand, we are developing the oxygen generation system that is smaller, lighter, and more energy efficient. In general, water circulation is indispensable for water electrolysis using a solid polymer electrolyte (SPE) (Figure 2). If the electrolysis unit is developed with a water/gas separation function, the oxygen production system will become simpler also(Figure 3). Just injecting only a quantity of water to undergo electrolysis, there is no need for gas-liquid separation as it is not necessary to circulate the water. All liquid water is electrolyzed, the hydrogen gas contains no liquid water. We aim to make a simple system that is more compact, lightweight, and energy efficient. Section 3, confirmed that oxygen generation with a water circulation-free system is possible, and evaluated characteristics of the prototype of the electrolysis unit.

II. Applying the ground demonstration system.

We've studied the research and development of electrolysis cells using a solid polymer electrolyte, and a water/gas separator using a membrane for the Advancement of the oxygen generation system. In a study of water electrolysis, electrolysis voltage and cross-leakage characteristics were promoted by improving the electrolyte membrane and the catalyst. Low electrolysis voltage means the possibility of water electrolysis at a higher current density. It leads to a compact and lightweight system. In addition, it leads to a reduction in the power of oxygen generation. This contributes to a power save in the system. Increasing the cross-leakage amount leads to an increase in the risk of a hydrogen explosion. Therefore, improvement of cross-leakage characteristics that are reducing the concentration of hydrogen in generated oxygen gas, or the concentration of oxygen in generated hydrogen gas, greatly contributes to safer system. Furthermore, higher regeneration efficiency of the air regeneration system is expected, because the improvement means highly pure gases.

Now, JAXA built a ground model of the air regeneration system for demonstration on the ISS, and the model has been tested. A system of the model is almost the same as figure 1. It is equipped with a 10 cell stack electrolyzer and a 4 stack membrane-type water/gas separator. A 4 Stack separator that achieves low pressure loss had already been developed. However, study of the electrolytic cell with improved membrane and catalyst was only a single cell test. So, we developed a 10 cell stack electrolyzer for the ground demonstration model.
So far, it has been confirmed that a 10 cell stack and a single cell stack have almost the same characteristics (low voltage, low cross-leakage).



4 stack membrane-type water/gas separator.

10 cells water electrolyzer

Figure 4 The separator and the water electrolyzer for oxgen generation unit in the ground demonstration model of the air revitalisation system.

Figure 4 is the separator and the water electrolyzer for the oxygen generation unit in the ground demonstration model of the air revitalization system. We placed the electrolyzer and the separator on the turntable to test the long-term operating characteristics of the electrolysis cell voltage, the differential pressure control of oxygen lines and hydrogen lines, cross-leakage, the gas dew point, and etc. As parameters we used: changed electrolysis current, line pressure, circulating water flow rate, and gravitational direction.

III. Study for progress of the oxygen generation system

In a conventional water electrolysis cell with a proton-conducting membrane, water is fed to both the cathode and anode sides of the membrane. This is to avoid insufficiency of water supply which can damage the membrane. It is possible to simplify the system by feeding water from only the anode side. This brings advantages such as lower weight, but creates a problem in that the generated gases are rich in water vapor. Therefore, it will be necessary to dry the oxygen to make it suitable for breathing by humans in space. The cathode water feed method (figure 2) also gives a simple system, but with relatively dry oxygen. In this method, water migrates to the anode side of the cell from the cathode side through the membrane. Although the generated hydrogen contains much water vapor, it is possible to obtain dry oxygen.

To reduce mass, size, and power of the oxygen generation system (figure 3), we attempted to build a system which doesn't need water circulation and a water/gas separation device. In the previous system (figure 2), water circulation was necessary as a water supply to the electrolysis cell in order to eliminate the generated hydrogen, and to cool the cell. However, previous studies have reported problems caused by the water circulation[5)]. When the water cycle is no longer needed, there was a possibility that these problems could be solved. What is more, the system size and mass could be reduced significantly. We expect a simple system by developing an electrolysis unit which has a water/gas separation function. Then by the reduction of pressure drops and the thermal efficiency on each part, it is expected that the system will save more power. In viewpoint of life-span or malfunction replacement, the simple system may have a favorable answer for future problems.

Experiment specification

The fabricated electrolysis unit (figure 5) has a cathode feed method similar to the JAXA conventional one. It has a water/gas separation function. Therefore, even without water circulation, the unit can supply the water required for the electrolysis to the MEA, and can extract only hydrogen gas. If there isn't water circulation, there will be a problem with the temperature distribution of the electrode. If there is water circulation, distribution of the temperature on the electrode is relatively uniform. If there isn't water circulation, there is a possibility of membrane damage by local high temperatures on the electrode. Although it is very difficult to check, we used a material which has high infrared transmittance installed in the internal viewing window of the electrolysis unit, and attempted to evaluate temperature distribution inside the cell by using an infrared camera. The exact amount of water required for the water electrolysis is supplied with a metering pump. A specification of the electrolysis unit is in table 1. The experiment environment is figure 6.

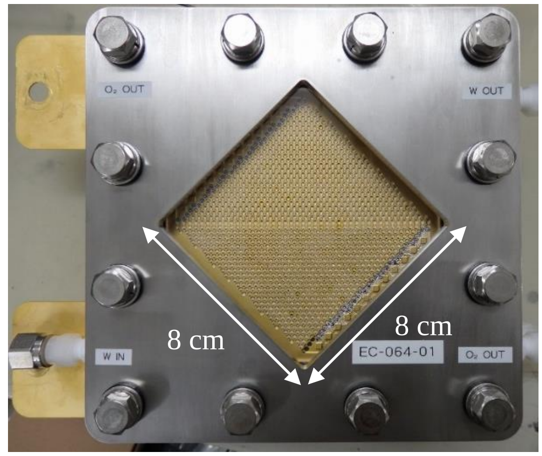


Figure 5 Electrolysis unit which water circulation is not required.
Electrolysis unit which has a water/gas separation function and is not required water circulation.

Table 1 Electrolysis unit specification

Electrode area	64 cm^2
Polymer electrolyte membrane	Nafion
Mass of electrolysis unit	3.76 kg
Feed method	Cathode feed

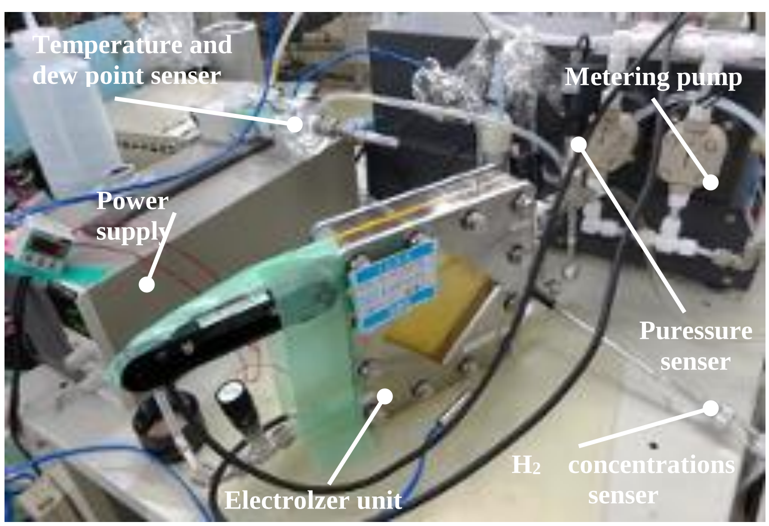


Figure 6 Experimental installation

Result and discussions

First, when there is no water circulation, we confirmed that it is safe for water electrolysis, and getting only hydrogen gas without water. Figure 7 represents a relationship between current density and electrolysis voltage. (a) is in no-water circulation. (b) is JAXA's previous Nafion electrolyzer with water circulation. (c) is JAXA's previous electrolyzer improved membrane and catalyst with water circulation. The mixture of water-hydrogen was not output from the electrolytic unit, and we confirmed that the voltages became steady. Electrolysis voltage is higher than the previous JAXA system. This is because we are using Nafion. If equipped with the MEA improved membrane and catalyst, the values become very close to (c) in figure 7.

Figure 8 represents hydrogen concentrations in generated oxygen (indicator of a cross-leakage), temperatures of hydrogen gas, and dew points of the hydrogen gas at current densities. From past experiences, the cross leak amount increases rapidly when the membrane is damaged. The concentration of figure 8 also shows that the electrolysis is not abnormal with the electrolysis unit. The temperature and the dew point of figure 8 are approximately the same. It shows that the hydrogen gas taken out contains almost saturated H_2O vapor .

In our past system, the pressure loss included the single stack electrolyzer, and the separator was from 20 to 100 kPa. The electrolytic unit needs 3 to 6 kPa for the water supply pressure, and can put out only hydrogen gas. It is a very low pressure drop.

Figure 9 is a view taken from the surface of figure 5 with an infrared camera. Conditions are at electrolytic current 0.8 A/cm^2 and the direction of gravity is from the top to bottom of figure 9. Water is supplied from the upper right direction in figure 9. The temperature at the bottom of the figure is lower, and the center top is the highest temperature. This is because these areas have enough water to electrolyze. Water supply comes from the upper right direction, and water is pulled to the lower side by gravity. The center part tends to lack of water. Water isn't distributed to the upper center part of the figure. If there is circulating water, gradient of temperature is generated in the direction from the upstream to the downstream of the flow. However, if there isn't circulation, the temperature distribution depends on the distribution of water including effects of surface tension and gravity on a MEA. If a multiplex cell stack is used for the experiment, the problematic heat would be expelled, and we would have to remove it. The new electrolysis unit was operated for a few hours. In this short time, water electrolysis voltage didn't indicate change.

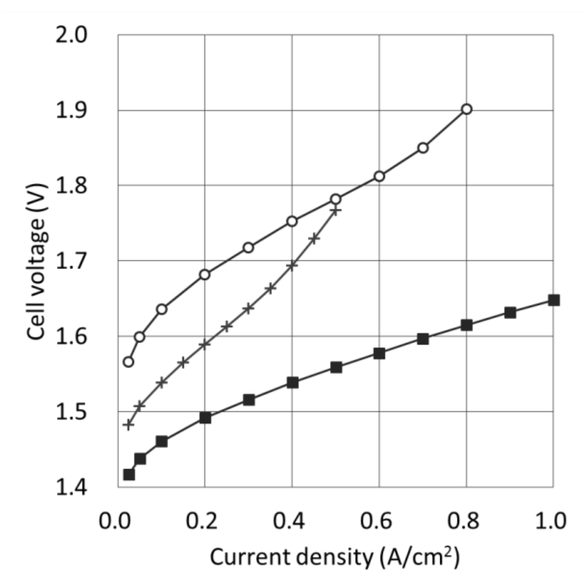


Figure 7 Polarization curves of new cathode feed electrolyzer and conventional reference cells.
○: (a) electrolysis unit with water/gas separation function in no-water circulation. ＋: (b) JAXA's previous Nafion electrolyzer in water circulation. ■: (c) JAXA's previous electrolyzer improved membrane and catalyst in water circulation.

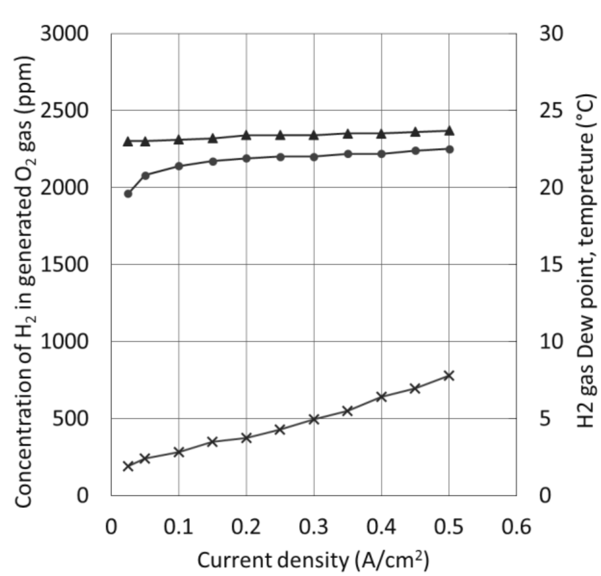


Figure 8 hydrogen concentrations in generated oxygen, hydrogen dew points and hydrogen temperatures at each current densities.
×: (a) hydrogen concentrations, ▲: (b) hydrogen temperatures, ●: (c) hydrogen dew points

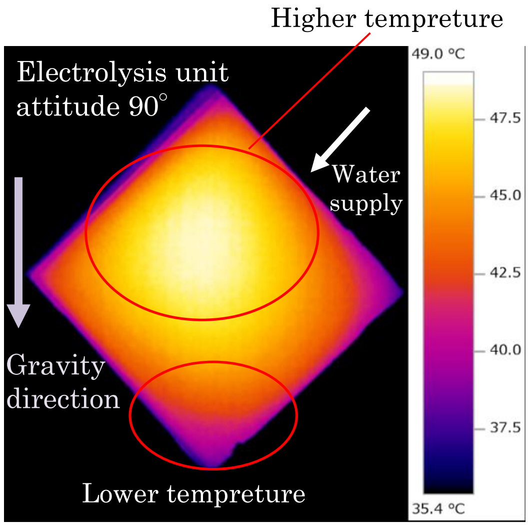


Figure 9 Temperature distribution in the electrolysis unit (current density 0.8 A/cm^2)

IV. Conclusion

In this paper, we describe our past research of the ground demonstration model, and development of the electrolysis unit for further improvement of the oxygen generation system. Summarize the findings obtained by this study and the future prospects.

- We applied the 10 cell electrolyzer and the 4 stack water/gas separator which use past studies of the ground demonstration model. The electrolytic cell and membrane-type separator has been evaluated on the ground demonstration model (the long-term operation is also included).
- On the other hand, we made a prototype electrolysis unit to promote compact, lightweight and power saving of the oxygen generation system. The electrolysis unit doesn't need water circulation, and has a water/gas separation function.
- Basic characteristics of the unit is good, and further improvement can be expected.
- We understood the temperature distribution inside the electrolysis unit.
- We will carry out acquisition of characteristics on long-term operation, and further heat distribution characteristics of the electrolysis unit.

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