WATER EXTRACTION EXPERIMENT ASSUMING LUNAR ICY REGOLITH FOR IN-SITU RESOURCE UTILIZATION ON THE MOON. S. Okamoto[1], J. Shimada[1], H. Meguro[1], T. Iwaki[1], S. Ukai[1], Y. Tanaka[2], S. Mori[2] and K. Fukaura[2], [1]Japan Aerospace Exploration Agency (JAXA), 2-1-1 Sengen Tsukuba-shi Ibaraki Japan, [2]JGC Corporation, 2-3-1 Minatomirai Nishi-ku Yokohama-shi Kanagawa Japan

Introduction: Even though tremendous effort is put into research to reduce the transportation cost to the Moon and Mars, it is still pretty expensive. Considering this, in-situ propellant production by the water on the Moon plays an essential role in enabling the sustainable exploration of the Moon and Mars. It will reduce the amount of propellant transported from the Earth for the following purposes: traveling on the Moon, returning to the Earth, and heading to Mars from the Moon.

To realize the transportation cost reduction, feasibility studies for the lunar propellant production plant that uses lunar water as its material have been conducted by JAXA (Japan Aerospace Exploration Agency) and its partner companies. Technical challenges have been prioritized and water extraction from lunar icy regolith is regarded as one of the key technologies due to its unprecedentedness and indispensability for in-situ water utilization.

Therefore, this research carried out experiments to extract water from regolith simulants. Extraction is conducted by manipulating the state change of water with heat, and various heating environments and methods are researched all over the world. For instance, CAST (China Academy of Space Technology) and DLR (German Aerospace Center) respectively experimented with a heated auger.[1][2] DLR also experimented with changing the shape of the regolith container.[2] Our research chose 2 heating methods, microwave and heating wire. The details are explained in the following sections.

Sample Preparation: The sample preparation is an important part of the experiment. To replicate the lunar icy regolith, the following procedures were conducted. First, the regolith simulant was heated for 6 hours to remove unnecessary contained water and impurities. Next, the simulant was mixed with methanol and aqueous ammonia. The mixed simulant was frozen in the freezer and then cooled further with liquid nitrogen to approximately -196 degrees Celsius.

Additives were selected based on the data from the LCROSS (Lunar Crater Observation and Sensing Satellite) mission. Impurities observed in the LCROSS mission can be classified into the following 3 categories; (a) be miscible rather than dissolve as a solute, (b) dissolves in water mainly as ions, (c) dissolves without ionization. For (a) methanol was chosen, and for (b) ammonia was chosen as a representative because they were easy to handle and had a big impact on downstream purification equipment. Both methanol and ammonia are not found in the air, so the risk of contamination during the experiment was low unlike carbon dioxide. It was an advantage as well. Materials in category (c) were assumed to be relatively easy to remove in purification equipment and were not selected in this experiment. In these processes, the expected existing state of water on the Moon was tried to be reproduced.

Experiment: The main experimental equipment was composed of the vacuum chamber and the cold trap (Fig. 1). Heating process was conducted in the vacuum chamber to mock the space environment, and extracted water was captured by the cold trap. The temperature in the vacuum chamber and cold trap and the pressure in the vacuum chamber were tracked. Fig. 2 shows the configuration of the experimental equipment. Each equipment was connected with bulbs and they were opened and closed respectively. It enabled the intentional manipulation depending on the elapsed time and the temperature. For heating, 2 methods were tested. The first method was microwave under the premise that it could heat quickly and evenly inside. Second, the heating wire was selected because of its simplicity and high-power efficiency.

While heating, the profile of heating temperature and time was adjusted aiming to decrease the amount of impurities that remained in the captured water. This process will ease the electrolysis which will be the next process in the propellant production. This technology is currently under patent application by JGC Corporation.

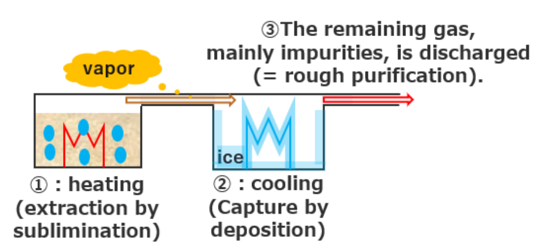

Fig.1 Overview of Experiment

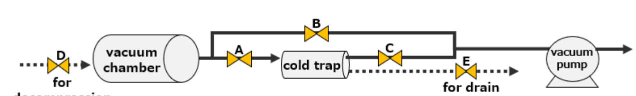

Fig.2 Configuration of Experimental Equipment

Results: Extraction of water from the regolith simulant was successful for both the microwave method and the heating wire method. The capture rate of water reached more than 80 % for the microwave heating experiment. The 2 heating methods are going to be compared in terms of feasibility including system mass and power consumption by analyzing the gained data of temperature change profile and power consumption profile. Water purification performance is another indicator to compare the 2 methods, so the remaining additives in the captured water will be examined.

Conclusion: This research achieved the water extraction from icy regolith simulant in the vacuum state. The water recovery rate reached more than 80 % when a microwave was used to heat. The heating process was also conducted by heating wire, the 2 heating methods are going to be compared in terms of feasibility.

The future goal of this research is to operate the water extraction system on the Moon. To achieve this, a continuation of the comparison of multiple heating methods and optimization of heating parameters and environments are planned as a first step. Sample preparation methods to replicate the existing state of water is also an essential part. Afterward, water extraction will be experimented on the Moon with other manipulations of the propellant production by constructing a demo plant. According to JAXA's current roadmap regarding space resource utilization, the beginning of the full-scale plant operation is targeted for 2040.

This work is led by JAXA in cooperation with JGC Corporation.

References:

[1] Lichen H. et al. (2021) *A novel auger-based system for extraterrestrial in-situ water resource extraction. Icarus,* 367. [2] Luca K. et al. (2023) *Design Investigation of Lunar Water Extraction*.