KINETIC INVESTIGATION OF WATER PRODUCTION FROM LUNAR SOIL SIMULANT BY HYDROGEN REDUCTION. T. Watanabe[1], S. Komatsuzaki[1], H. Kanamori[2], and S. Aoki[2], [1]Dept. Environmental Chemistry and Engineering, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan, [2]Shimizu Corporation, Institute of Technology, 3-4-17 Etchujima, Koto-ku, Tokyo 135-8530, Japan.

Introduction: In-situ resource utilization (ISRU) technologies will be much more important for the engineering purposes, as future missions for the Moon and Mars exploration and development are advancing to a more active phase. Manned lunar missions will require the use of locally derived materials since transportation from the earth requires much time, cost, and labor. For life support and spacecraft propulsion, oxygen that can be produced from water is the most essential substance. Therefore, water-production from the lunar soil is a primary concern for ISRU.

Over 20 processes of oxygen production on the moon have been proposed [1]. Among these processes, oxygen production employing hydrogen reduction is the most feasible process [2]. In this process, ilmenite contained in the lunar soil is reduced with hydrogen.

$$FeTiO_3(s) + H_2(g) \rightarrow Fe(s) + TiO_2(s) + H_2O(g) \quad (1)$$

Ilmenite can be easily reduced since the free energy formation in this reaction is relatively low.

Oxygen is subsequently produced by electrolysis of water. Hydrogen produced in reaction (2) can be recycled in reaction (1).

$$H_2O \rightarrow H_2 + 1/2O_2 \quad (2)$$

Understanding of the hydrogen reduction mechanism of ilmenite is important for the mission of utilizing the lunar soil.

The authors' research group in Japan has been conducting a ground-engineering work on experimental missions for lunar resource utilization. The goal of the research program is to conceptually design an ISRU experiment system for unmanned water-production on the moon, and to define essential technological breakthroughs. As part of the research program, an experimental study on hydrogen reduction of the lunar soil has been performed to design a chemical reactor of the water-production. Some requirements for the reactor design were also determined from our research achievements.

Experimental Apparatus: A fixed-bed reduction reactor and lunar soil simulants were prepared for our water-production experiments. Change in chemical composition of the lunar soil simulant caused by the reduction, the temperature dependence of the reaction rate, and the characteristics of the rate-controlling process were quantitatively evaluated. The schematic diagram of the experimental apparatus is shown in Fig. 1. The measurement system for water-production rate was improved on the previous apparatus reported in 2000 [3]. The apparatus consists of a reactor, a furnace, and a measurement system including a moisture meter, gas flow meters, pressure gauges, and thermocouples, with connecting the A/D converter and a personal computer for data acquisition. Water-production rate were monitored every 0.5 s.

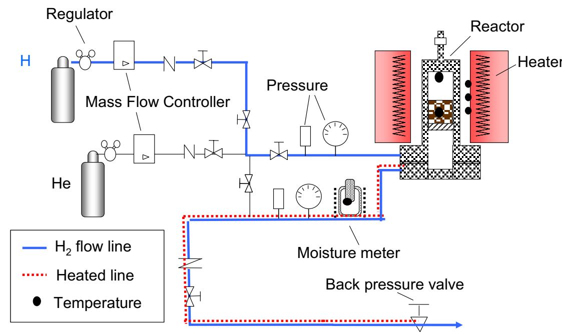

Fig. 1 Lunar soil reduction system by H_2.

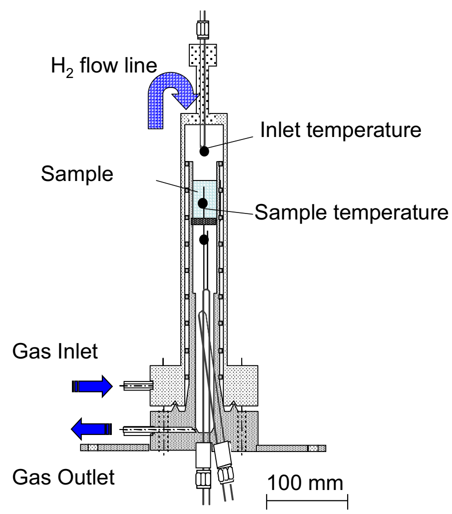

Fig. 2 Reactor of lunar soil reduction by H_2.

The schematic diagram of the reactor is shown in Fig. 2. A reactor is made of Inconel-600, and consists of an inner tube (30 mm i.d., 275 mm long) and an outer tube. The lunar soil simulant is held in the upper part of the inner tube by placing ceramic screen filters with 10 μm-openings and glass wool on the top and bottom ends of the lunar soil simulant. Hydrogen flows up through a preheating gap between the inner and the outer tubes, and reacts with the lunar soil simulant. Hydrogen with produced water is sent to the moisture meter after the outlet. Experiments were conducted with varying of the reaction temperature (1073-1323 K), the hydrogen flow rate (2-6 SL/min), the sample weight (5-15 g), and the particle size of the stimulant (20, 70, 120 μm).

The sample used in the experiments is the lunar soil simulant (Shimizu Corp., Japan) with similar chemical and mechanical properties of the lunar soil. The chemical composition of the sample is shown in Table 2. The lunar soil simulant has the mean particle size of 70 μm, bulk density of 1.55×10^3 kg/m^3, specific gravity of 2.94.

Results and discussion: Effect of temperature on the water-production rate is shown in Fig. 3. Higher temperature leads to higher water-production rate up to 1273 K. Effect of temperatures on the cumulative produced water is shown in Fig. 4. Larger amount of water was produced at higher temperature up to 1273 K. Water-production rate and the cumulative water-production at 1323 K is smaller than those at 1273 K. Partial sintering or melting of glassy contents occurred at higher reaction temperature, resulting in the unreacted FeO and Fe_2O_3 at the inner part of the particle of the lunar soil simulant.

The analysis of chemical composition of the lunar soil simulant before and after reduction was carried out. Ferric oxide (Fe_2O_3) is completely reduced and ferrous oxide (FeO) is slightly reduced by hydrogen. Other components contained in the lunar soil simulant were not influenced by the hydrogen reduction.

Mission Conception: The proposed experiment mission system is mounted on a lunar lander, and transported from the earth to the lunar surface. The system is composed of a solar furnace, a reactor with hydrogen storage, some devices for moisture measurement, chemical analysis, and sample handling. After its landing on the moon, a small amount of lunar soil is sampled and carried to a reactor vessel with a robotistic machine, and then solar heat is supplied to a heating furnace integrated with the reactor. The oxygen-production system after the water-production is proposed in Fig. 5 with indication of the operation temperature and the energy transfer of the process.

Conclusion: Hydrogen reduction process is optimum for oxygen-production on the moon. FeO and Fe_2O_3 contained in the lunar soil simulant are the major reduced components. The reduction temperature at 1273 K and smaller particle are recommended for the water-production form the lunar soil.

References:

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Table 1 Composition of lunar soil simulant.

Component	Lunar Soil Apollo14 [wt%]	Lunar Soil Simulant [wt%]
SiO_2	48.1	50.3
Al_2O_3	17.4	16.3
CaO	10.7	9.4
MgO	9.4	4.4
FeO	10.4	8.7
Fe_2O_3	-	4.4
Others	3.8	6.5
Total	99.8	100.0

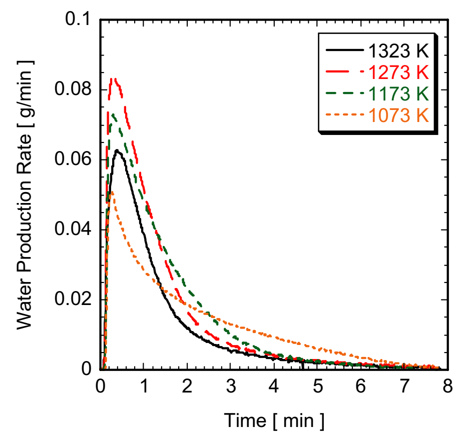

Fig. 3 Effect of temperature on water-production rate.

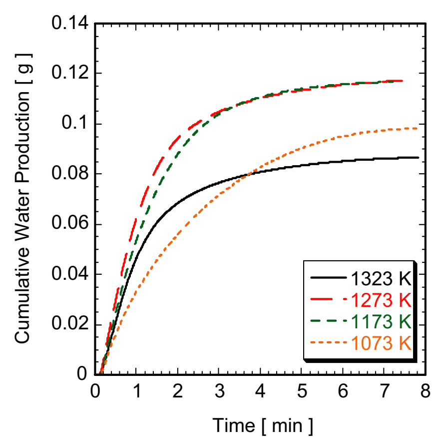

Fig. 4 Effect of temperature on cumulative water-production.

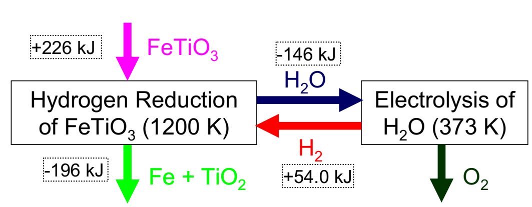

Fig. 5 Process diagram for oxygen-production by H_2 reduction of ilmenite at process temperature.