Experimental Results of Newly Developed Techniques for Volatile Extractions Using Lunar Simulant and Oxides

K. J. Kim[1] • Marcel Hess[1]

[1] Korea Institute of Geoscience and Mineral Resources (KIGAM) | Contact: kjkim@kigam.re.kr

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ABSTRACT

A soil heating reactor system was developed to analyze gas release from lunar regolith simulants and to evaluate Molten Regolith Electrolysis (MRE) under simulated lunar conditions.

The system operates under vacuum and can reach temperatures up to 1,500 °C. During controlled heating to 1,000 °C over 50 minutes, released gases were continuously measured using two Residual Gas Analyzers (RGA).

Results provide critical insight into the temperature thresholds required for in-situ resource utilization (ISRU) on the Moon.

RESEARCH OBJECTIVES

① Develop a vacuum-compatible heating reactor reaching 1,500 °C

② Quantify volatile release (H_2O, O_2, CO_2) from lunar regolith simulants

③ Identify temperature thresholds for ISRU-relevant gas extraction

④ Demonstrate Molten Regolith Electrolysis (MRE) feasibility for oxygen and metal recovery

EXPERIMENTAL SETUP

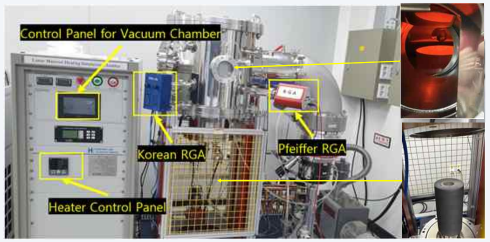

Fig. 1 — Schematic of the KIGAM soil heating reactor system

Max Temperature	1500 °C
Operating Pressure	High Vacuum ~10^{-6} Torr
Heating Profile	RT → 1000 °C / 50min
Gas Analysis	Dual RGA (KR+DE)
Crucible	Electrically heated, mobile

KEY RESULTS — Gas Release vs. Temperature

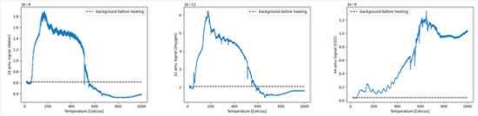

Fig. 2 — Partial pressure of released gases as a function of temperature

Around 200 °C, the release of water vapor and oxygen reached its peak. This suggests that moisture and oxygen adsorbed or weakly bound to the regolith simulant were actively desorbed or decomposed at that temperature. Afterward, the release began to decrease and returned to background levels at 650–700 °C. This indicates that most of the volatile oxygen and water vapor had been removed (reduced) within this temperature range. After 800 °C, the amount of oxygen released showed a slight increase again. This may suggest that some of the mineral components within the lunar soil simulant began to undergo thermal decomposition at high temperatures, resulting in the release of oxygen.

The amount of carbon dioxide (CO_2) extracted up to 600 °C increased steadily with temperature. This indicates that carbonate minerals or organic materials gradually decomposed within this temperature range, releasing CO_2. After 600 °C, the CO_2 release remained nearly constant. This suggests that most CO_2 precursors had already decomposed by 600 °C, or that the decomposition rate of the remaining precursors had become very slow. The regolith simulant mainly released moisture and oxygen at relatively low temperatures (~200 °C), which appears to originate from adsorbed volatile substances. Carbon dioxide was continuously released up to a relatively higher temperature (~600 °C). At temperatures above 800 °C, the re-release of oxygen due to thermal decomposition of the minerals themselves was observed.

TEMPERATURE-DEPENDENT VOLATILE BEHAVIOR

~200 °C	H_2O and O_2 peak — desorption of adsorbed volatiles
~600 °C	CO_2 rises and plateaus — decomposition of carbonates / organics
650–700 °C	H_2O & O_2 return to baseline — adsorbed phase exhausted
>800 °C	Secondary O_2 rise — thermal decomposition of mineral phases

LUNAR CONTEXT & ISRU RELEVANCE

Lunar regolith hosts adsorbed solar-wind volatiles, implanted hydrogen, and oxide minerals that serve as precursors for water, oxygen, and metals. Understanding the precise temperature thresholds at which each volatile is liberated is essential for designing efficient ISRU plants on the Moon's surface, particularly for sustained human exploration and propellant generation.

METHODOLOGY

1. **Sample Loading**
   Lunar simulant placed in electrically heated crucible inside vacuum chamber
2. **Vacuum Pump-Down**
   Turbo + rotary pumps evacuate chamber to high vacuum
3. **Controlled Heating**
   Linear ramp RT → 1,000 °C over 50 min; up to 1,500 °C achievable
4. **Gas Monitoring**
   Two RGAs continuously record H_2O, O_2, CO_2 partial pressures
5. **MRE Evaluation**
   Molten state assessed for electrolytic O_2 + metal extraction

KEY FINDINGS

- ✓ Successful design and operation of a 1,500 °C vacuum heating reactor
- ✓ Two distinct volatile release regimes identified — adsorbed (≤700 °C) vs. structural (>800 °C)
- ✓ CO_2 release confirms carbonate/organic precursors decompose by 600 °C
- ✓ Secondary O_2 peak >800 °C signals mineral-phase breakdown — key for MRE
- ✓ Reactor platform validated for future MRE oxygen-production studies

CONCLUSIONS & FUTURE WORK

The newly developed KIGAM soil heating reactor successfully demonstrates volatile extraction and oxygen liberation from lunar regolith simulants under simulated lunar vacuum conditions.

The dual-stage gas-release behavior provides a thermodynamic roadmap for designing future ISRU facilities.

Next-phase work will integrate Molten Regolith Electrolysis (MRE) at >1,500 °C to recover high-purity oxygen and metallic phases for sustained lunar surface operations.

ACKNOWLEDGEMENTS

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RESEARCH HIGHLIGHTS

1,500 °C	**50 min**	**RGA**	**3 Species**
Max Operating Temperature	Controlled Heating Ramp Duration	Residual Gas Analyzers (KR + DE)	H_2O, O_2, CO_2 Real-time Tracking