A Review on the Comparison of Volatile Evolution from a Lunar Simulant, conducted at KIGAM

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Introduction

Harvesting Lunar Resources: Volatile Extraction
Why it matters: In-Situ Resource Utilization (ISRU) on the Moon is crucial for future lunar exploration. Volatiles are essential and ubiquitous on the Moon
Foundation: Decades of Apollo sample analysis provide invaluable data for developing lunar volatile extraction payloads.
Our Research: We're conducting research on volatile extraction using **lunar simulants**, identifying key aspects and future research directions for lunar **volatile recovery**. Furthermore, we are developing **oxygen extraction** techniques like Molten Regolith Electrolysis (MRE) and new method using e-beam.

Experimental Setup

- Volatile extraction experiment using varying lunar simulant and temperature settings [1]
- Apollo samples [2]:
  - Originally 200 mg to 500 mg samples
  - Melting points from 1,130°C to 1,150°C
  - At 700°C, at this temperature, H_2, ^4He, ^3He, H_2O, N_2, CH_4, CO, and CO_2 are released
- Two heating stages at 500°C and 700°C. (Figure 2-5)
- Test target sample weights and temperatures for KIGAM's
- Lunar Volatile Extraction Demonstrator (LUVED).
- Volatile extraction using an e-beam gun

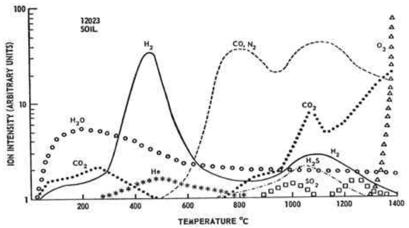

Figure 2: Gas release pattern for Apollo 12 soil 12023,9[3} [2]

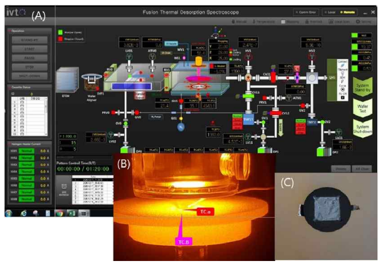

Figure 2: Experimental Setup [1]

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Volatile Extraction Experiment

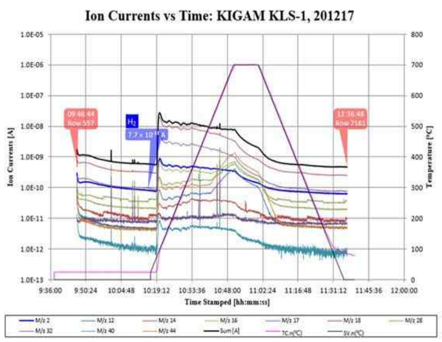

Figure 3: Ion current of gas release as a function of time and temperature. [1]

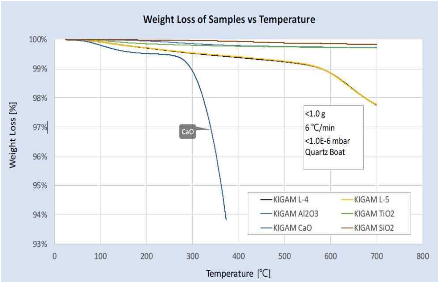

Figure 4: Weight loss of samples as a function of temperature [1].

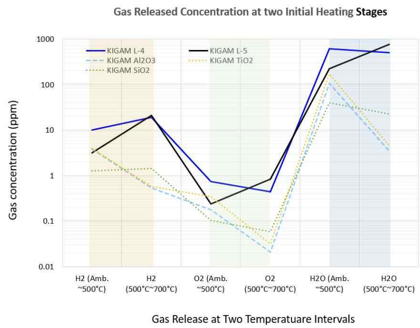

Figure 5: Gas release during two initial heating stages [1].

Volatile Extraction Experiment (Continued)

Table 1: Concentrations are given for two temperature ranges. "amb" corresponds temperatures of up to approximately 500°C and otherwise to temperatures between 500°C and approx. 700°C. [1]

Sample ID	Sample Type	Weight (g)	H_2 (amb)	H_2	O_2 (amb)	O_2	H_2O (amb)	H_2O
KIGAM L-4	Lunar Simulant	0.9486	9.88	1.90×10^1	7.27×10^{-1}	4.43×10^{-1}	6.09×10^2	5.01×10^2
KIGAM L-5	Lunar Simulant	0.9367	3.12	2.08×10^1	2.36×10^{-1}	8.31×10^{-1}	2.21×10^2	7.65×10^2
KIGAM Al_2O_3	Oxides	0.9687	3.79	5.37×10^{-1}	1.75×10^{-1}	2.07×10^{-2}	1.06×10^2	3.46
KIGAM TiO_2	Oxides	0.9788	3.88	5.69×10^{-1}	3.44×10^{-1}	3.16×10^{-2}	1.67×10^2	4.49
KIGAM CaO	Oxides	0.9746	3.58	0	1.91	0	4.52×10^3	0
KIGAM SiO_2	Oxides	0.9594	1.26	1.41×10^{-1}	1.02×10^{-1}	5.86×10^{-2}	3.94×10^1	2.27

Gas release from e-beam gun

- Setup of e-beam in vacuum chamber (see Figure 6)
- E-beam gun can heat sample quickly to over 1,100°C.
- Good preliminary results for producing oxygen using this method.
- Oxygen concentration reached 100× the background level after heating (see Figure 7)

The concept of this new technique has been referenced in Moses et al. 2024 [3].

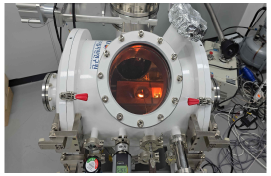

Figure 6: Vacuum chamber and e-beam setup.

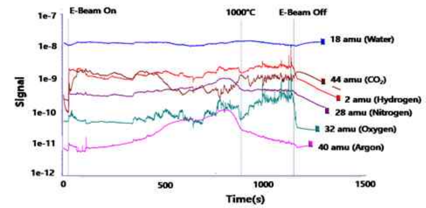

Figure 7: Gas release of e-beam experiment measured using Residual Gas Analyzer (RGA)

Conclusion

Paving the Way for Lunar Resource Utilization
Our preliminary research confirms that **volatile extraction from lunar regolith is feasible at a practical temperature of 700°C**, a crucial finding for the design of the Korean lunar lander's **LUVED payload**.
By leveraging insights from Apollo samples and modern missions, we've demonstrated initial gas extraction from lunar simulants, highlighting the distinct release of key volatiles like H_2, O_2, and H_2O.
Looking Ahead: Enhancing ISRU Capabilities Our future work will focus on ion-implanted lunar simulants, which will allow for more accurate and efficient laboratory-based volatile ex- traction experiments. This will better mimic the solar wind interactions on the Moon, providing invaluable data for:

- Developing small-scale ISRU payloads for early missions.
- Developing volatile extraction methods using an e-beam gun and MRE techniques for preliminary studies
- Designing larger, more robust volatile extraction devices for sustained lunar operations.

This research is a vital step towards realizing in-situ resource utilization across the lunar surface, paving the way for a sustainable human presence on the Moon.

References

[1] Kim, K.J. SRR 2024.
[2] Gibson E.K and Johnson, S.M. 1971 Lunar Science Conference, Abstract #1057, Houston, 1971.
[3] Moses, R. et al. J. Aerosp. Eng. Mech. 2024. 8(1):636-649.

Acknowledgments

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