LUWEX Preliminary results: Water Extraction, Capturing, and Purification from Lunar Icy Regolith Simulant.

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Introduction: Lunar water extraction is a key technology for In-Situ Resource Utilization (ISRU), enabling the production of life support consumables and propellants from lunar resources. Water ice deposits in permanently shadowed regions (PSRs) are a primary target for future lunar missions, as they could reduce reliance on Earth-based resupply. Extracting, capturing, and purifying water from these deposits is a complex process requiring specialized techniques that can function under extreme environmental conditions.

The LUWEX project was designed to experimentally validate a complete end-to-end water extraction process in a simulated lunar PSR environment. Unlike previous studies that focused on individual steps, LUWEX integrated thermal extraction, vapor transport, cold trapping, liquefaction, and purification into a single system. The primary goals were to assess extraction efficiency, validate system scalability, and analyze water purity for electrolysis and potential human consumption.

Experimental Setup and Methodology: The extraction, capturing, and liquefaction experiments, shown in Figure 1, were conducted in a dusty Thermal Vacuum Chamber (TVAC) at Technische Universität Braunschweig, originally designed for cometary physics research [1]. The chamber provided a low-pressure and cryogenic temperature environment simulating permanently shadowed regions (PSRs) on the Moon. The water extraction subsystem was designed to hold up to 15 kg of icy regolith simulant and could repeatedly cycle through extraction and capture processes.

The thermal extraction process involved heating the sample in a crucible while stirring to ensure uniform sublimation. Water vapor released from the icy-regolith mixture traveled toward a cold trap, where it was deposited on the cold fingers. Once a sufficient amount accumulated, the ice was delaminated and transferred to the liquefaction chamber. Within this chamber, the partial pressure generated by the sublimated water vapor facilitated the phase transition of the ice into liquid water.

Following liquefaction, the collected water was transferred outside of the TVAC to the purification subsystem, which was designed to remove contaminants such as lunar dust particles and dissolved volatiles. The purified water is analyzed against NASA and WHO standards for human consumption and ASTM standards for electrolytic water to determine its suitability for ISRU applications.

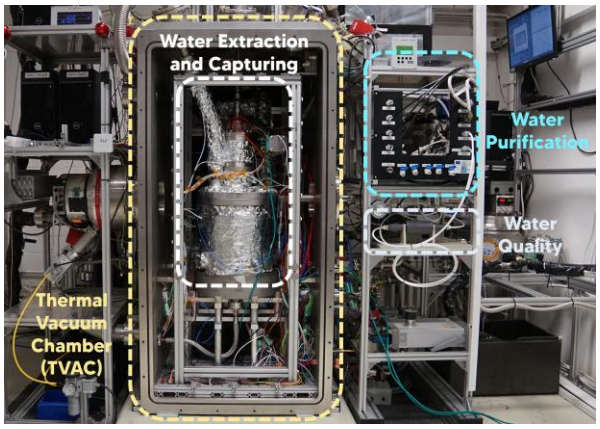

Figure 1: LUWEX system hardware at the Technical University of Braunschweig.

Another critical component of LUWEX is the development of a high-fidelity unfused discrete icy regolith simulant, which replicates the expected properties of possible lunar ice deposits. This simulant consisted of micrometer-sized ice particles mixed [2] with a lunar regolith simulant, displayed in Figure 2. The goal was to mimic the thermal and physical behavior of real icy lunar regolith. Following results from the LCROSS mission [3],a series of contaminants were considered. Eventually, methanol was added to the icy mixture.

Figure 2: Icy-regolith sample with 5% ice mass content.

Results and Discussion: The LUWEX system demonstrated high water recovery efficiencies, with results showing:

- The validation of a complete ISRU water process chain up to TRL 4, and approaching TRL 5 regarding extraction and capturing capabilities in a relevant test environment.
- Over 2 litres of water was captured and liquefied from simulant material.
- The system demonstrated a water vapor capture efficiency of up to 90%, indicating that approximately 10% of the vapor was lost to the surrounding chamber environment.
- Overall recovery efficiency exceeding 70% after optimizing operations, and reaching an energy efficiency of 50 grams of extracted water per kWh.
- All captured water was purified.

The recovered water samples showed significant contamination, as can be seen in Figure 3. Results of the purification subsystem will be presented in future works.

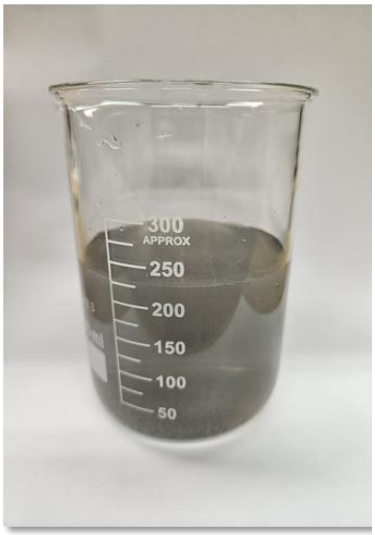

Figure 3: Recovered contaminated water after liquefaction.

Conclusion and Future Work: The LUWEX project successfully demonstrated a complete, integrated system for lunar water extraction, capturing, liquefaction, and purification under simulated permanently shadowed region (PSR) conditions. The results confirm that high water recovery efficiencies are achievable, confirming feasibility for lunar ISRU. Data post-processing will give more insights in the exact performance of the systems, and will help improve the design.

Future research will focus on enhancing system scalability and recovery efficiency, with efforts directed toward increasing throughput and improving energy efficiency. Additional work is required to optimize thermal control, and the cold trapping concept of operations to minimize water losses and maximize recovery rates.

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