Trade-off and optimization for Lunar water extraction

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Introduction

Water is an essential resource for space exploration, for both robotic and human exploration. It is foreseen that in the future, these resources can be used to produce rocket propellant by electrolyzing water into its components Hydrogen and Oxygen or by astronauts for drinking water and breathable oxygen. This Space Resource Utilisation (SRU) would reduce the cost of spacefaring significantly. Especially considering the development of multiple (commercial) lunar landers currently, a lunar economy will soon become more accessible, which further drives the need for water extraction equipment. According to the International Space Exploration Coordination Group (ISECG), there is a need for more knowledge on the drivers for the water extraction process and specifically how to minimalize potential losses [1]. Multiple methods to extract water from lunar regolith (e.g. such as excavating, thermal mining, electric arc mining) are already envisioned, and this research aims to select the most promising concept, and then design, test, and establish best engineering practices for Lunar Water Extraction. See figure 1 for an overview of Thermal Extraction Methods.

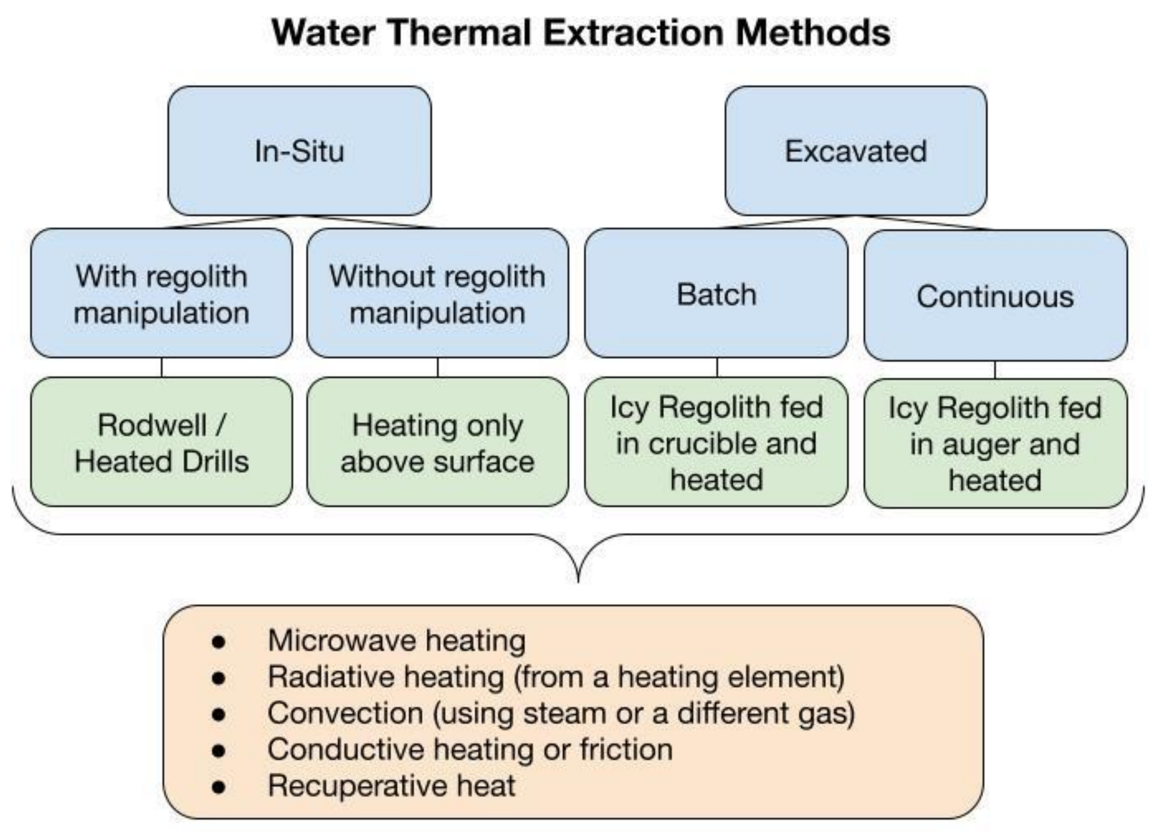

Figure 1: Possible methods to thermally extract water from lunar regolith.

Problem Statement

To extract water on the Lunar surface, several challenges are posed. One of the most obvious one is the hazardous Lunar environment. Depending on where one wants to go to extract water, the accessibility of the raw resource can differ greatly, ranging from simply on top of the lunar surface (or some meters below), to deeply hidden in dark and cold craters.

Currently, the exact state of how the water resides on the Moon is not known. Most knowledge from the state of water comes from remote observation missions, and these are unable to sense how the water exist on the Moon. The design of the water extractor in this research will focus on being the most suited for a future mission. This means that the durability, efficiency, and reliability will likely be important design drivers, depending on the exact scenario.

Eventually, the goal is to separate the water (or water group molecules) from the surrounding regolith to a highest degree attainable within bounds. This would form the basis for establishing best practices for extracting water.

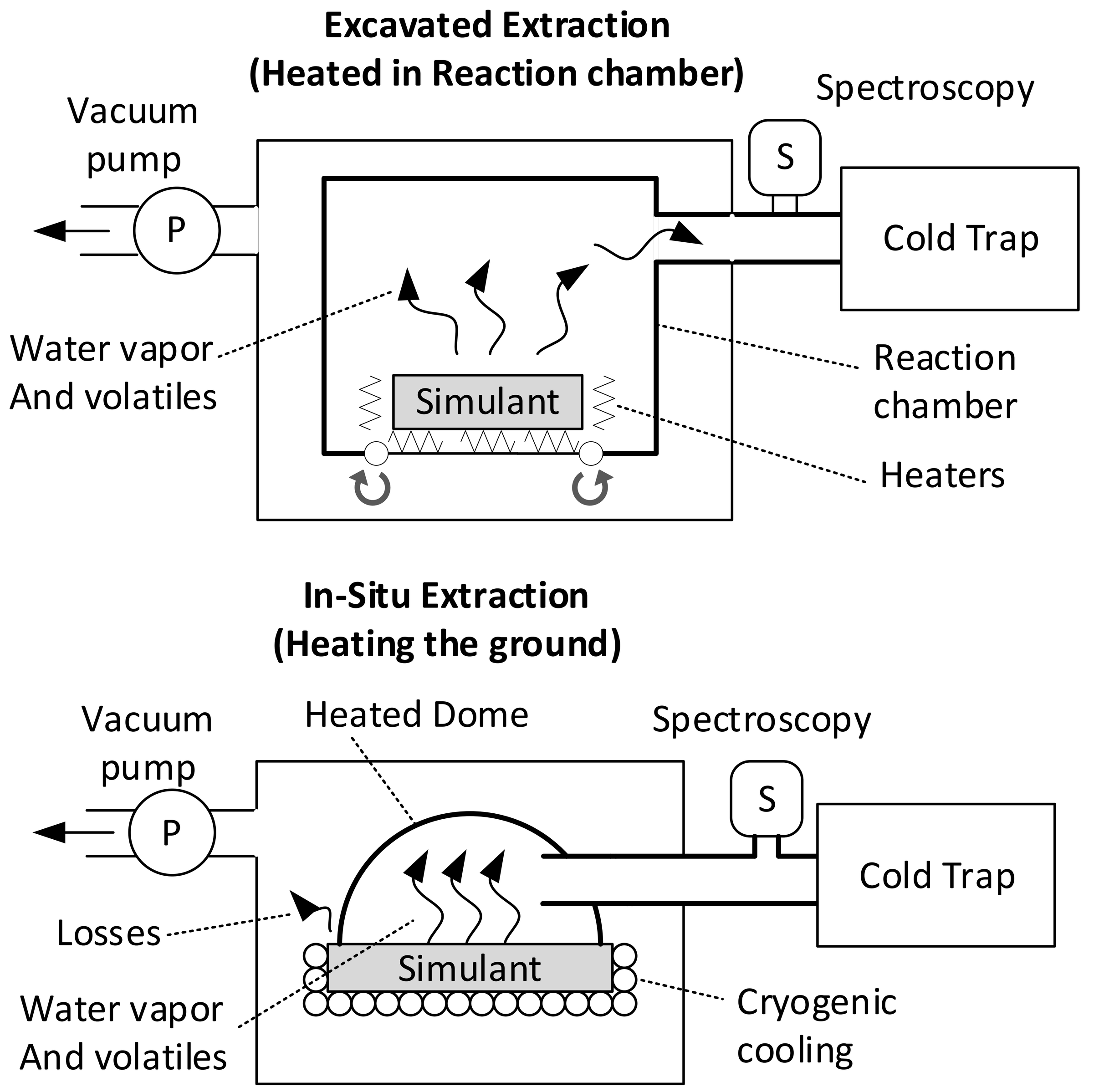

Figure 2: Examples of thermal water extraction test setups. On the left an example of an excavated sample inside a reaction chamber is presented. On the right an example of the heated dome concept is presented.

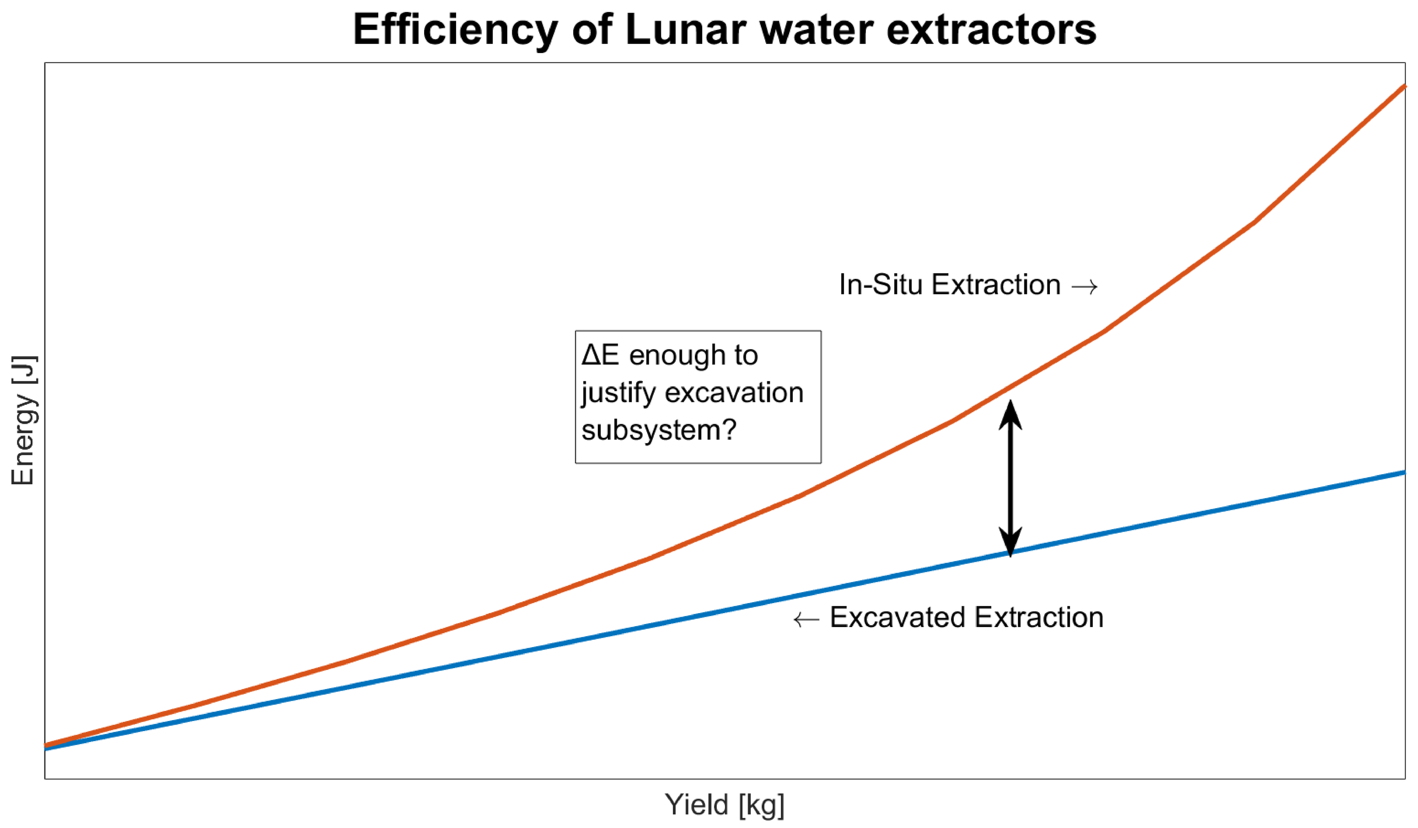

Figure 4: Expected efficiency behaviour of thermal water extractors.

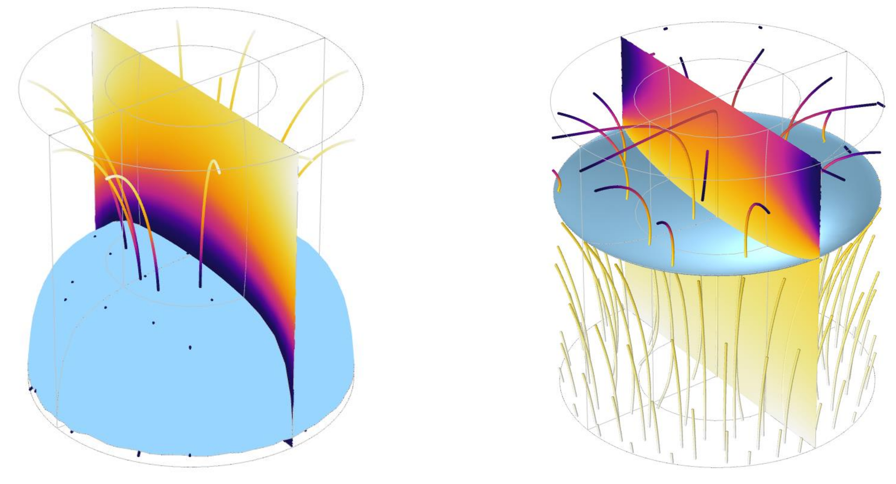

Figure 3: Typical heat and mass transfer of thermal water extraction. On the left the regolith sample is heated from all sides. On the right the sample is only heated from the top.

Methods

Trade-off

The first step will be to prepare the system engineering trade-off. The parameters for selecting the best water extractor system will be defined before the design itself will start, and the scenario in which they will be utilised will be set (location, state of the water, etc.). Then, the next step is to design multiple water extractors to a degree where these can be compared to each other. For this, requirements (coming directly from the selection criteria, functional, operational, etc.) will need to be established for each design. Both a quantitative and a qualitative trade-off shall be performed, since the fidelity of the designs is likely not enough information to accurately compare them to each other. Also, factors like complexity are hard to define in numbers, but should not be excluded in a selection. An example of expected energy demands per yield is presented in figure 4.

Simulations

To further understand the behaviour of outgassed water vapour within the water extractor system, and to gain insight in the requirements of the other systems such as the capturing device and the heating device, the designs will be simulated. Not only will this help with performing the trade-off, it will also help in predicting the results from the proposed experiment. Once these effects have been properly simulated, the individual parameters that govern them can be tampered with in order to create an optimal solution, as well as feed this information in a concept of operations which can consequently also be optimized from a mission point of view. An early result of the simulations is presented in figure 3.

Prototype Experiment in TVAC

After the system engineering trade-off is performed, and the selected design is optimized through simulation, a laboratory test will be conducted.

During these TVAC tests, certain functions will need to be tested. Depending on the selected method, these functions might differ. As is shown in figure 2, two potential test setups are considered, the in-situ extraction and the excavated extraction.

Planned Outcomes

- Insight into system engineering design choices for lunar water extractors.
- Prototype of a water extractor.
- Larger scale TVAC water extraction test with ~5 kg of regolith in cryogenic temperatures and high vacuum.
- Novel method of ice integration it regolith (TBD). Individually created ice particles mixed with dry regolith.

References

[1] International Space Exploration Coordination Group, “In-Situ Resource Utilization Gap Assessment Report,” 2021.

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