Design Investigation of Lunar Water Extraction

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1. 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. Recent discoveries have confirmed the presence of ice at the Lunar south pole. In this work, which is a continuation of the work presented in [1], the design parameters of 4 types of methods for thermal water extraction on the Moon are investigated. These methods are the in-situ surface heating method, the in-situ heated rods method, and the crucible method in different variations, as can be seen in figure 1. The goal is to find the most optimal way to extract water from the lunar surface.

Additionally, this poster will present some early results from the EU *LUWEX* project.

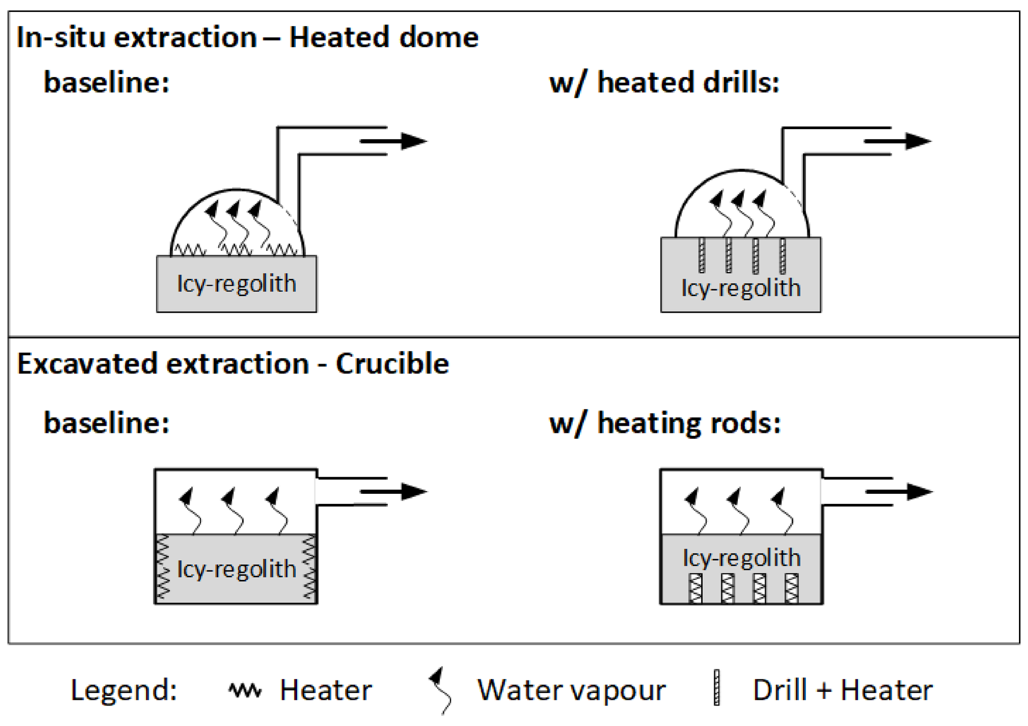


Figure 1: Schematic of examples for thermal water extraction methods.

2. Designs

The methods investigated are the in-situ surface heating, in-situ heated rods and a sealed reaction chamber. The sealed reaction chamber is extended with a dynamic version, a rotating drum. In figure 2 this design illustrates the drum in DEM Simulation software *Becker3D*. In table 1 the parameters investigated in this study are presented.

Table 1: Design parameters for each thermal water extractor design.

In-situ surface heating	In-situ heated rods	Reaction chamber
Power density	Number of rods, length of rods, diameter of rods, spacing between rods	Method of applying heat
Emissivity of dome	Power density, power gradient	Size
Dome size	Dome size	Excavation rate

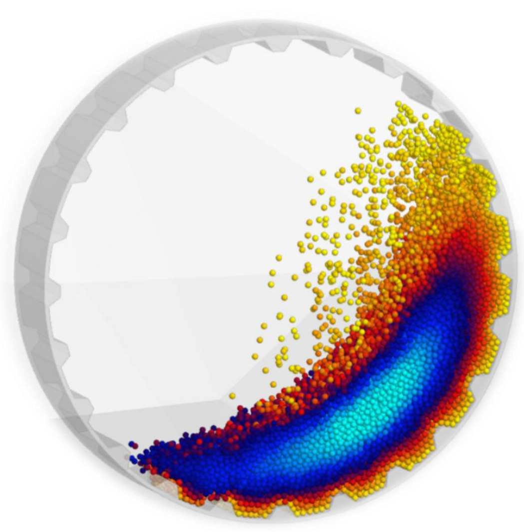


Figure 2: Rotating drum of particles for increasing the effective thermal conductivity; achieving ~10 K / min for significant decrease in water extraction time [2].

3. Methods

COMSOL Multiphysics 6.1 is used to simulate the designs. The designs of figure 1 are implemented where the icy-regolith is modelled as a solid containing ice and regolith. This mixture of ice and regolith contains the phase change material. Heat can be transferred to the ambient environment through radiation. Heat fluxes are applied at the curved surface in figure 3 for the crucible method and at the top surface in figure 4 for the in-situ method. Only when the latent heat of water is surpassed in an element, the ice is sublimated.

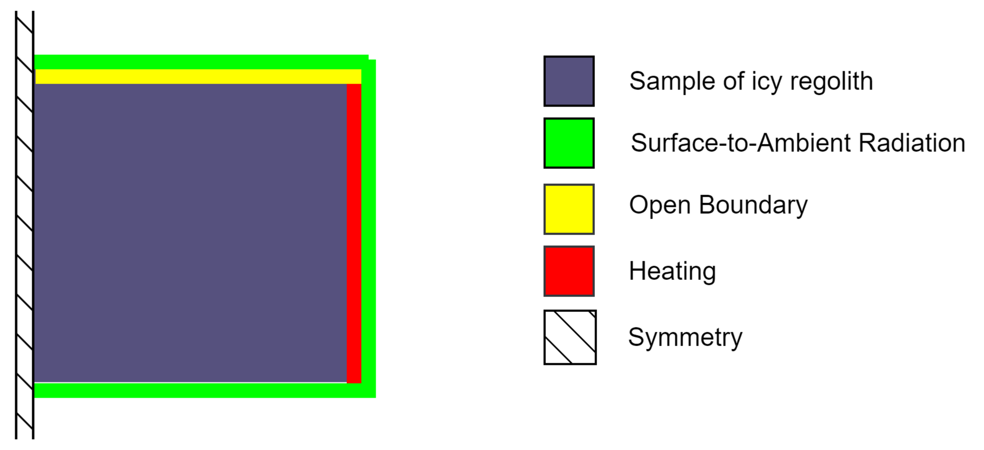


Figure 3: Boundary conditions for heating inside crucible after excavation.

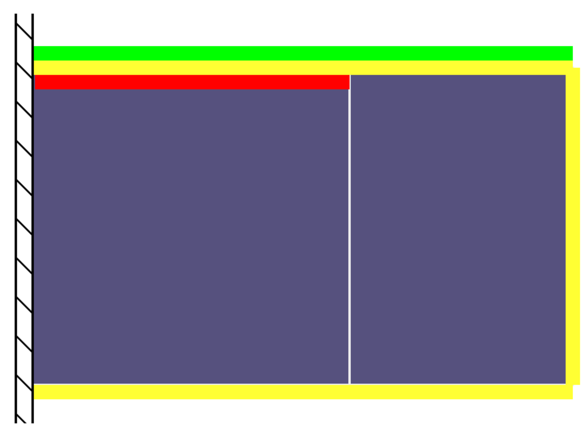


Figure 4: Boundary conditions for in-situ surface heating and in-situ rod heating. Rods are not depicted here.

4. Results

The total time-dependent water yield is shown in figure 5 for the 5% water content in-situ surface heating, in-situ heated drills and the baseline crucible, respectively. In these results, it can be clearly observed that the heated drills and the crucible have much higher yields than the simple in-situ surface heating.

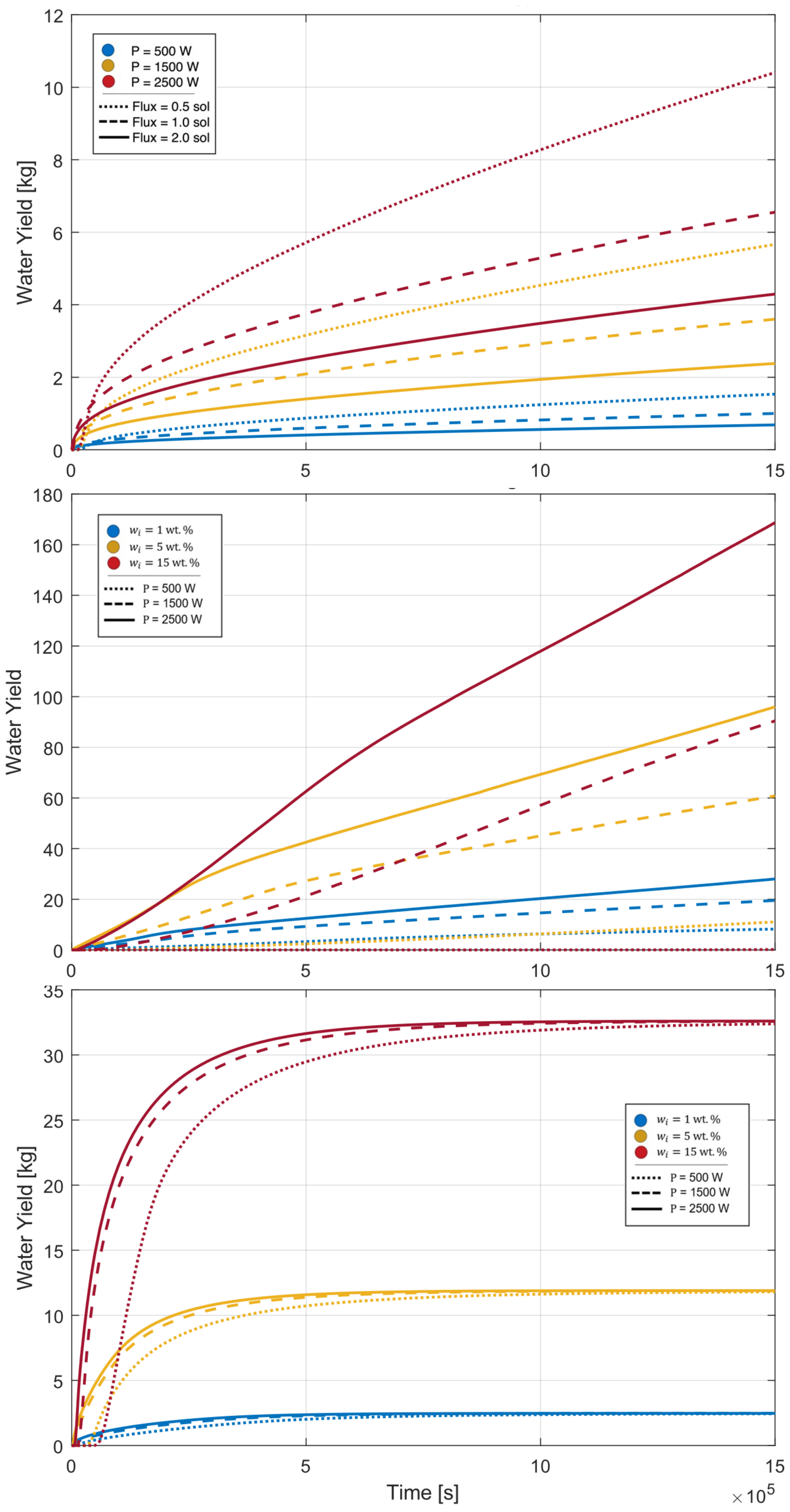


Figure 5: Water yield for in-situ surface heating, in-situ heated drills, and the baseline crucible after excavation [3].

LUWEX - Validation of Lunar Water Extraction and Purification Technologies for In-Situ Propellant and Consumables Production

The *LUWEX* project will use the experience from all the simulations presented in this poster for large scale water extraction experiment in a TVAC. The test will integrate both the water extraction and the water vapour capturing, as well as the water purification. In figure 6, a schematic of the complete test setup is presented, up until the storage after extraction. The hardware inside the dashed line will be surrounded by a could shroud with a temperature of 80 Kelvin, imitating the lunar environment. These tests are scheduled to take place in the summer of 2024.

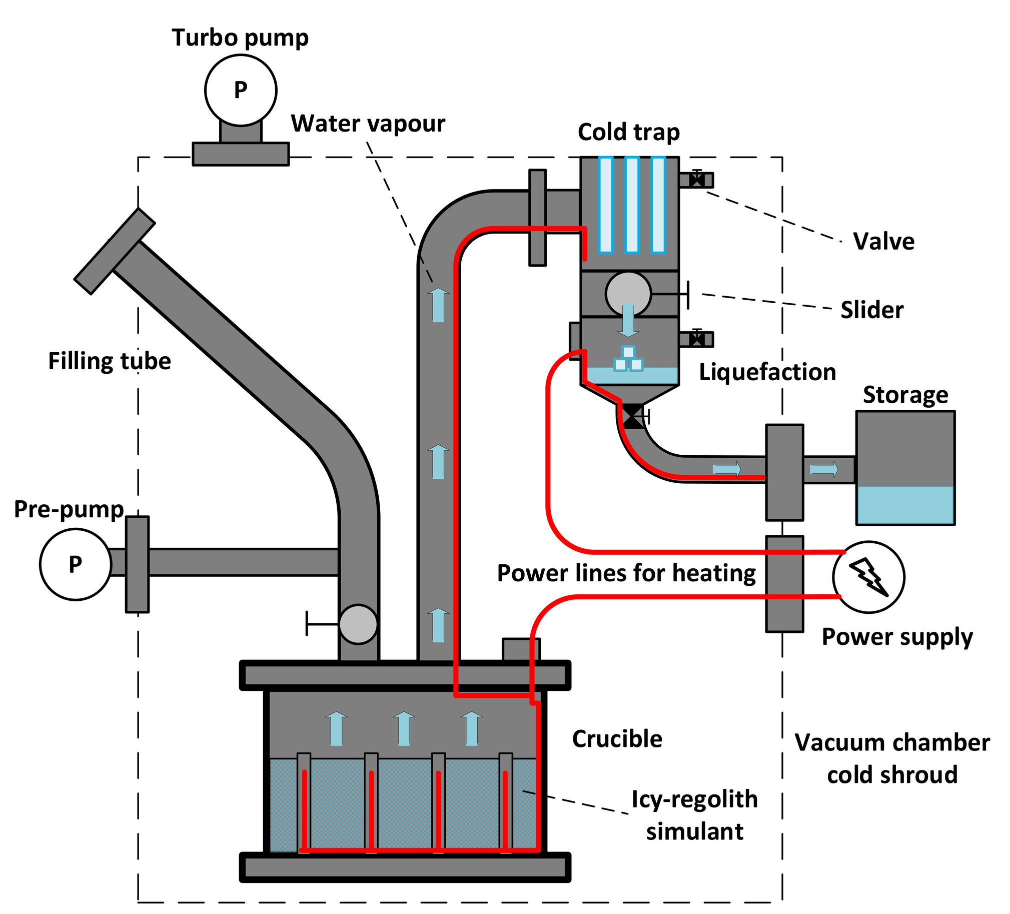
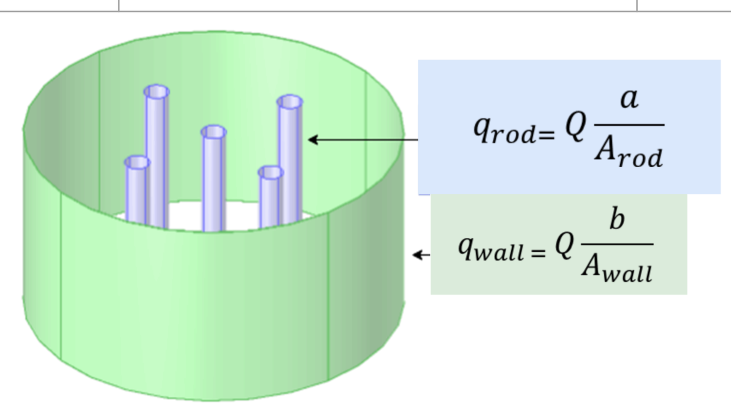


Figure 6: LUWEX Test setup for water extraction and capturing. Crucible dimensions: Ø = 30 cm, H = 27 cm

Table 2 shows the design parameters for experiment design. For *LUWEX* the number of heated elements, its radii, power distribution and water content are determined to be most contributing and selected as design optimizers. In figure 7 the COMSOL implementation is shown.

Table 2: Design parameters for *LUWEX* thermal water extraction.

Variable		Unit
N	Number of rods	-
R_r	Radius of rod(s)	m
Q	Power	W
C_i	Initial water content	%
a	Coefficient, where $a + b = 1$	-
b	Coefficient, where $a + b = 1$	-



$$q_{rod} = Q\frac{a}{A_{rod}}$$

$$q_{wall} = Q\frac{b}{A_{wall}}$$

Figure 7: Heat conditions; inward heat flux from wall and elements.

The results in figure 8 show the time of complete extraction decreases when implementing a higher number of heated elements. Integrating design optimization, decreases extraction time with 30% approximately. However, a balance must be struck between what is practical and what is optimal. Increasing Q to 1500 W reduces the extraction time by a factor of about 3, as expected.

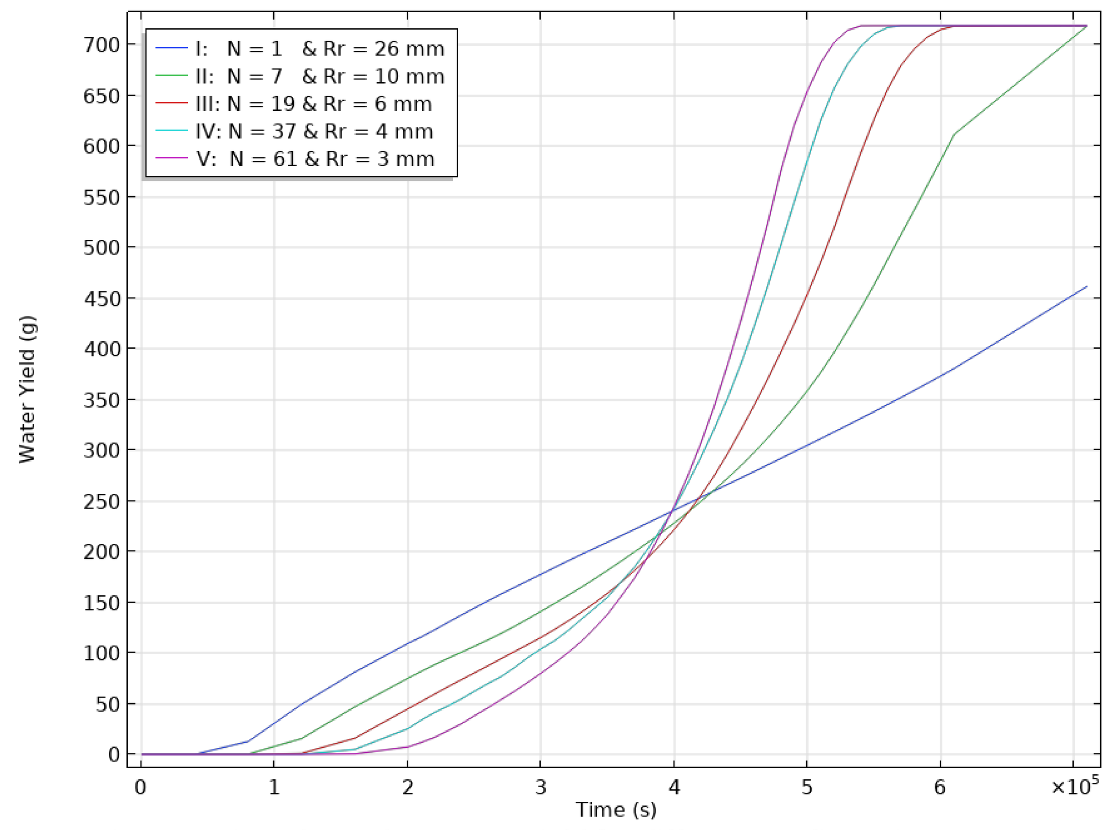


Figure 8: Time-dependent water yield for different configurations; Q = 500 W; C_i = 5%.

Visit https://luwex.space/ or scan the QR code!

References

[1] L. Kiewiet, N.M. Hab, F.M. Marchese, R. Freer and P. Zabel, Trade-off and optimization for thermal Lunar water extraction system. (2022), International Astronautical Federation (IAF).
[2] Becker 3D GmbH, (2023) Heat Transfer. ThreeParticle R6.0.7.
[3] N.M. Hab, Modeling, Simulation and Comparison of Lunar Thermal Water Extraction Methods for Space Resource Utilization LPE-MA 2022/01. (2022), Master's Thesis, German Aerospace Center, DLR.

This work is part of the DLR internally funded young investigator group "Synergetic Material Utilization" (SMU) established 2021 at the Institute of Space Systems in Bremen, Germany. The group focuses on research and development of ISRU technologies for Moon and Mars exploration.

The project LUWEX is funded through the Horizon Europe framework programme of the European Union with the grant number 101081937.

Funded by the European Union