Review of Water Capturing Devices for Lunar ISRU

Christoph Kalis[1,2], Luca Kiewiet*[1], Mart Heitkamp[1], Henning Wache[1], Alessandra Menicucci[2] and Paul Zabel[1]

[1]German Aerospace Center (DLR), Institute of Space Systems, Bremen, Germany
[2]Delft University of Technology, Faculty of Aerospace Engineering, Delft, Netherlands
*luca.kiewiet@dlr.de

1. Introduction

The use of resources present on celestial bodies, known as In-Situ Resource Utilization (ISRU), is becoming more and more important in space exploration due to the high cost of launching mass into orbit. ISRU would enable long-term manned operations and permanent (robotic) presence on extra-terrestrial bodies. Water is considered to be one of the most important resources for further space exploration and is currently investigated for extraction and purification on the future manned Lunar base envisioned around 2025. Previous research focused on the extraction of water from regolith but little work has been done to find ways on how to capture and liquefy the water vapour after its extraction.

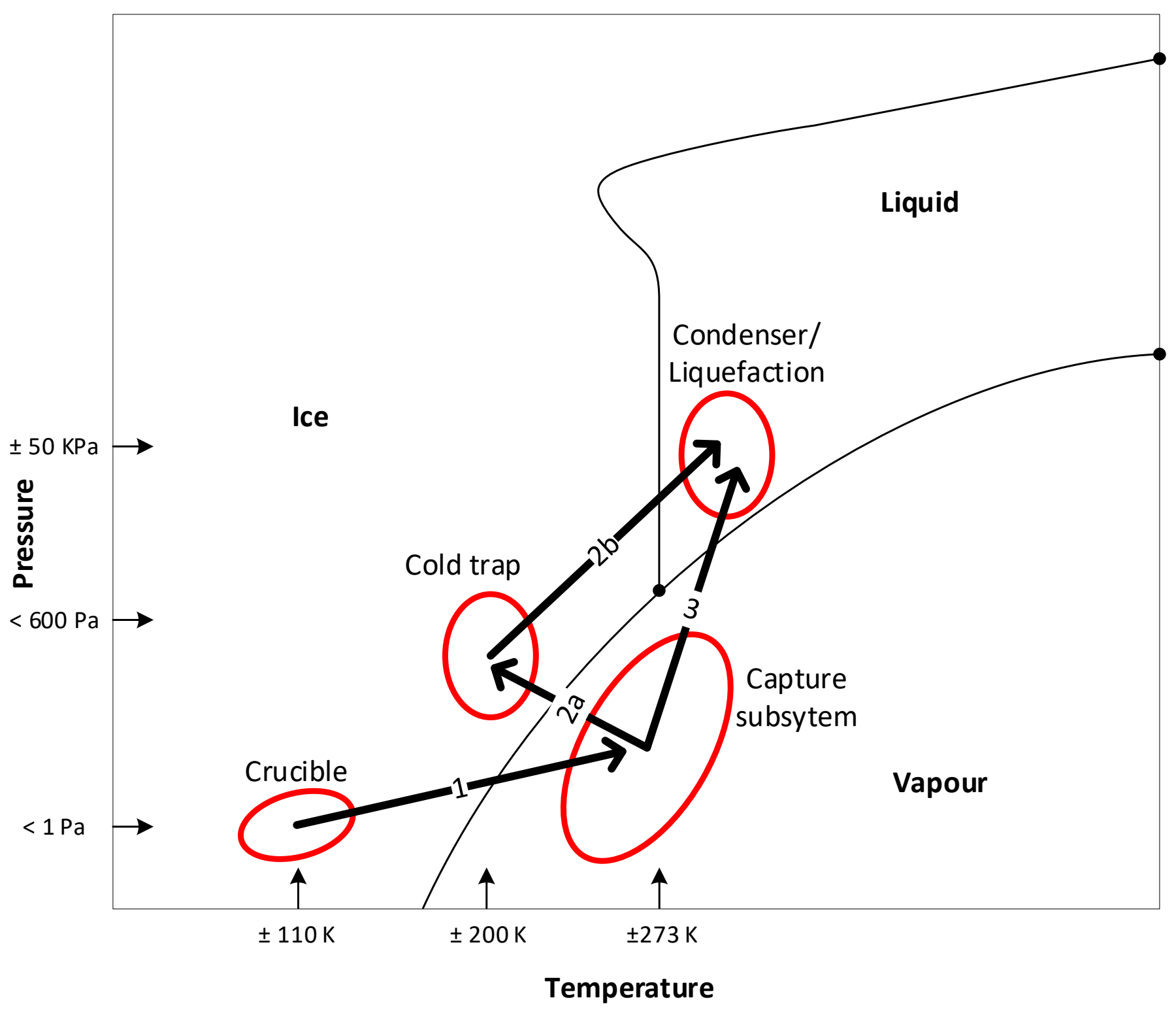


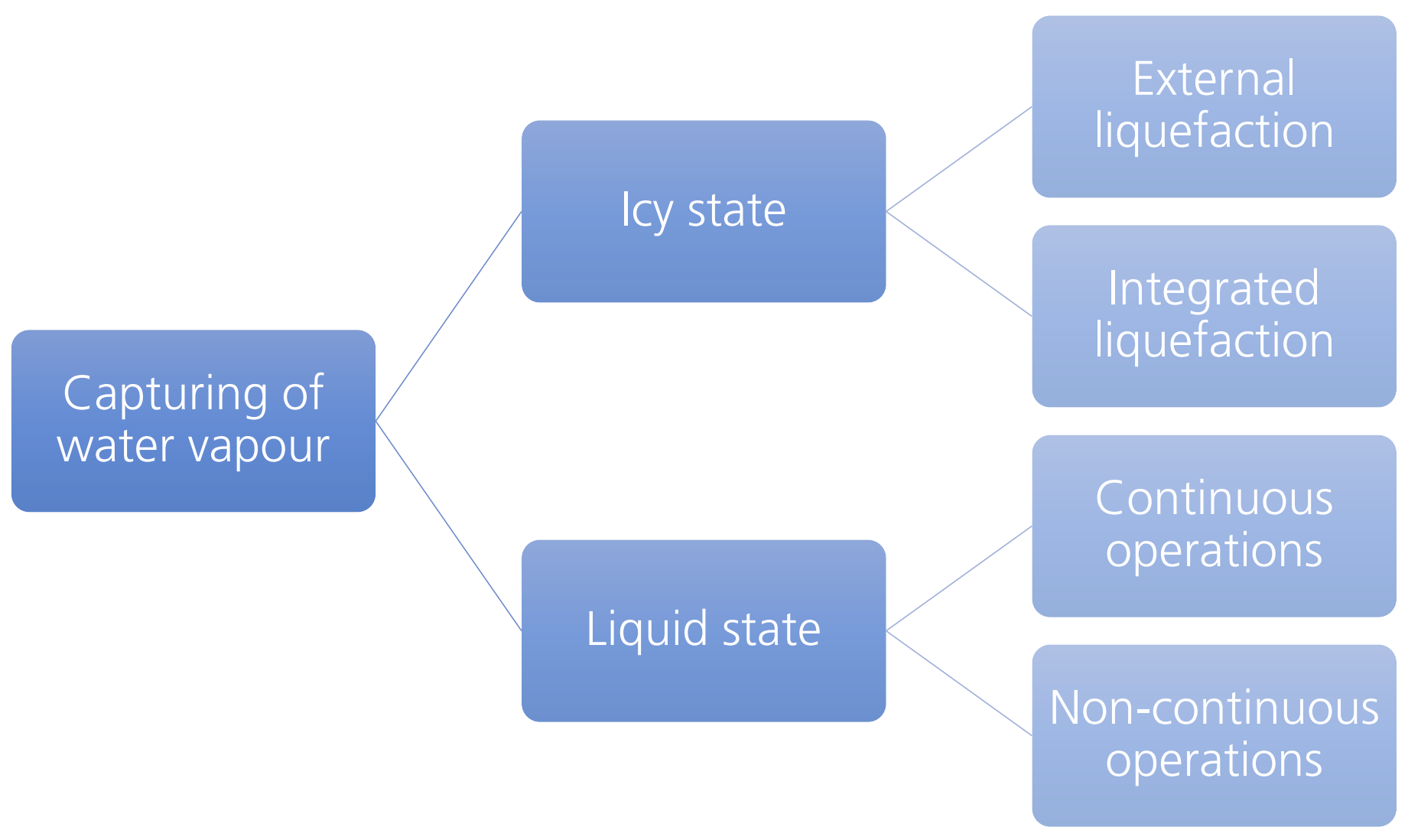
Figure 1: Schematic phase diagram with process overview. Path 2 shows how water can be captured as a solid, and path 3 as a liquid.

Thermal extraction is currently the preferred method for winning water, meaning heat is applied to the water ice regolith mixture resulting in the sublimation of ice and outgassing of the water vapour. This vapour is then captured and liquefied, as can be seen in figure 1. If sufficient temperature and pressure is present in the reaction chamber, a collection as liquid on the bottom of the chamber is theoretically possible. Unfortunately, the regolith has a high saturation with liquid water of around 16%. The residual water in the regolith would be too high and thus efficiency of the collection is likely too low. See figure 2 for the setup to test this.

Figure 2: Test-setup water in lunar regolith (saturation occurs at around 16%).

2. Potential Solutions

A cold trap is a cold surface to which the water vapour coming from the extraction system can deposit onto as a solid, after which it can be considered captured and secured. In this scenario, liquid water occurs after the capturing in a solid state. The gathered ice needs to be in an environment where liquid water can exist. Whether this change in pressure and temperature takes places directly in the capturing system (internal liquefaction) or whether the ice is detached from the capturing system and processed in another location (external liquefaction) needs to be decided.



Capturing of water vapour
Icy state
External liquefaction
Integrated liquefaction
Liquid state
Continuous operations
Non-continuous operations

Figure 3: Design option tree for vapour capturing.

The options for capturing in liquid state can be divided in continuous and non-continuous operations. For continuity, a constant flow of water vapour to the condensing surface at sufficient pressure and temperatures above the triple point is needed. This could be realized with a pump between the extraction subsystem and the capturing subsystem, since the liquid phase is undesired in the extraction subsystem. A high pressure in the crucible is unwanted since the water should only be in solid or gas state during extraction. These options are visualized in figure 3.

3. Preliminary Design of LUWEX

In Figure 4 an overview of the entire LUWEX experiment design is presented. A needle valve between the cold trap chamber and the vacuum chamber controls the vapour flow towards the actual cold trap itself and prevents the pressure rising too much. A slider separates the cold trap chamber from the liquefaction chamber to have a contained environment during liquefaction. In Figure 5 a preliminary CAD drawing of the relevant systems is presented. In the crucible, the water vapour has a temperature of around 273K after heating the regolith. This refers to a saturation pressure of 470 Pa which is then also present in the cold trap and liquefaction. Present volatiles in the icy-regolith sample are water ice, methanol, ethanol, CO2. The cold trap has to withstand these volatiles and is designed in such a way, that these volatiles are not deposited on the cold fingers.

The design was driven by volume constraints of the chamber and size of the slider which separates the cold trap and the liquefaction.

The goals of this baseline design were as follows:

1. As much cold trap area as possible for maximal ice mass and thus water vapour capturing.
2. Long residence time of the vapour for lower losses leading to a higher efficiency.
3. High liquefaction volume to lower the need for melting cycles for a higher total collection rate.

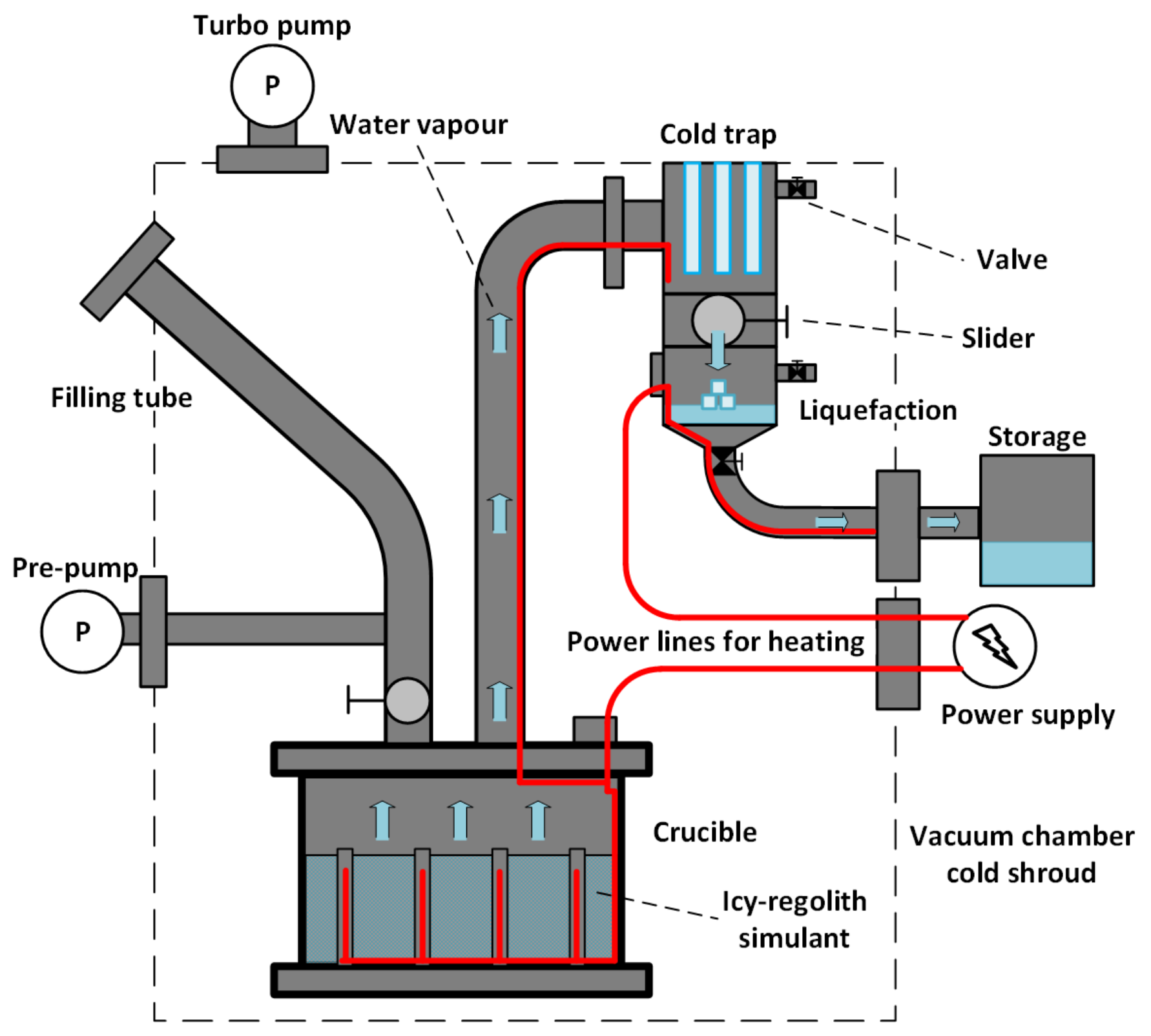


Figure 4: Schematic of the LUWEX experiment inside the TVAC.

The main reason for the decision of capturing as a solid, meaning cold trapping, was less complexity, since there is no need to rise the pressure between the crucible and the capturing system.. The condenser needs pumps and valves with pressure control to function efficiently and optimally. Besides, the condenser needs to maintain a higher temperature than the cold trap for it to work. The cold trap can make use of the cold Lunar environment. Also, less heat and control schemes are required to achieve the desired temperature and pressure ranges. Yet, the system is less controllable because pressure is more sensitive to unwanted condensation.

In future systems with cold trapping, the liquefaction might not occur directly after the capturing, so the intermediate storage could be in icy state. This reduces the storage complexity and favours the design with a cold trap.

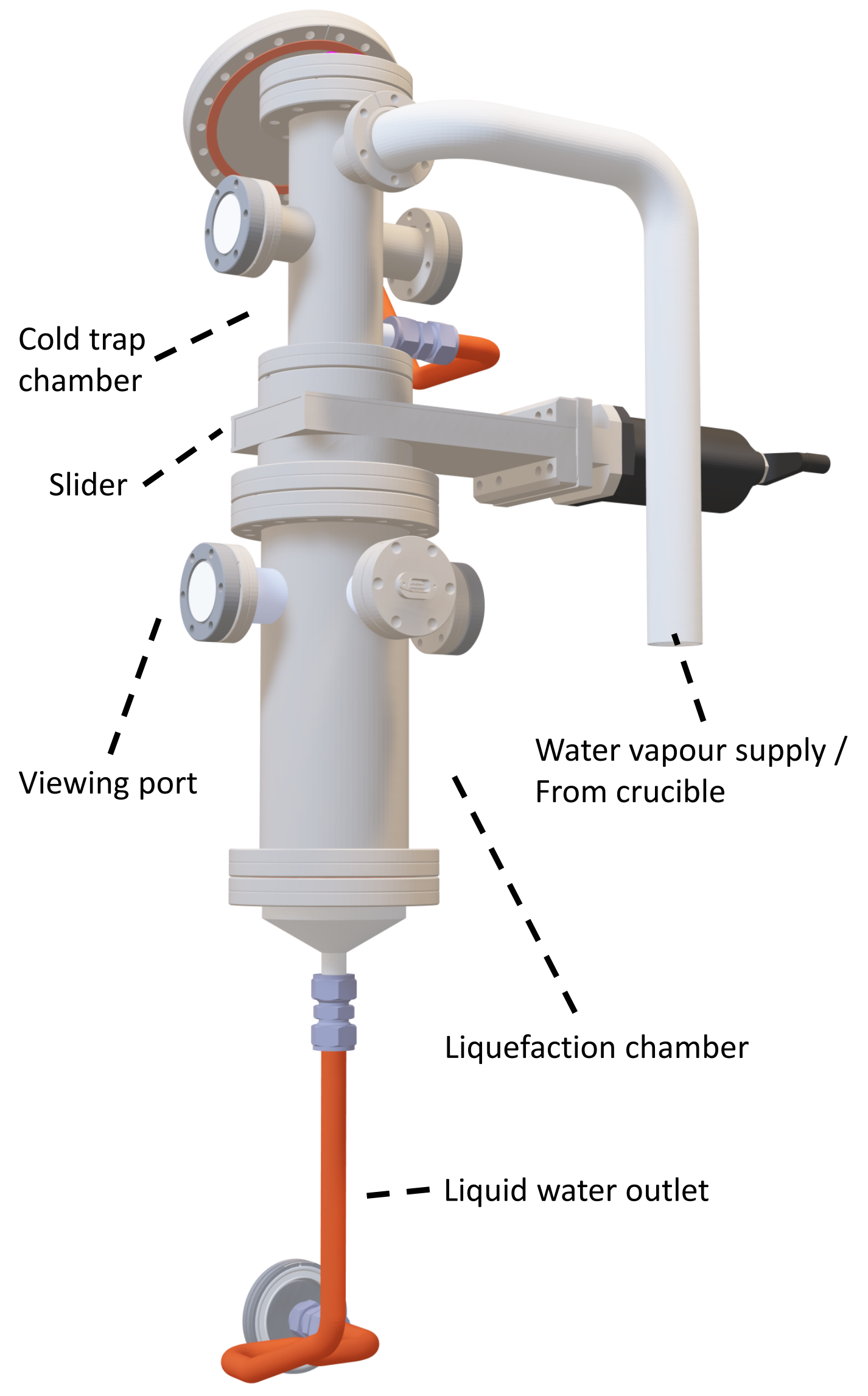


Figure 5: Model of the cold trap and liquefaction.

4. Cold Trap Experiment

Since there is little experience about capturing water vapour in low pressure environments, and specifically so for the purpose of In-Situ Resource Utilization, a small-scale test was conducted to see how effective it would be to capture water vapour on the Moon using a cold trap. Figure 6 shows the setup of this experiment.

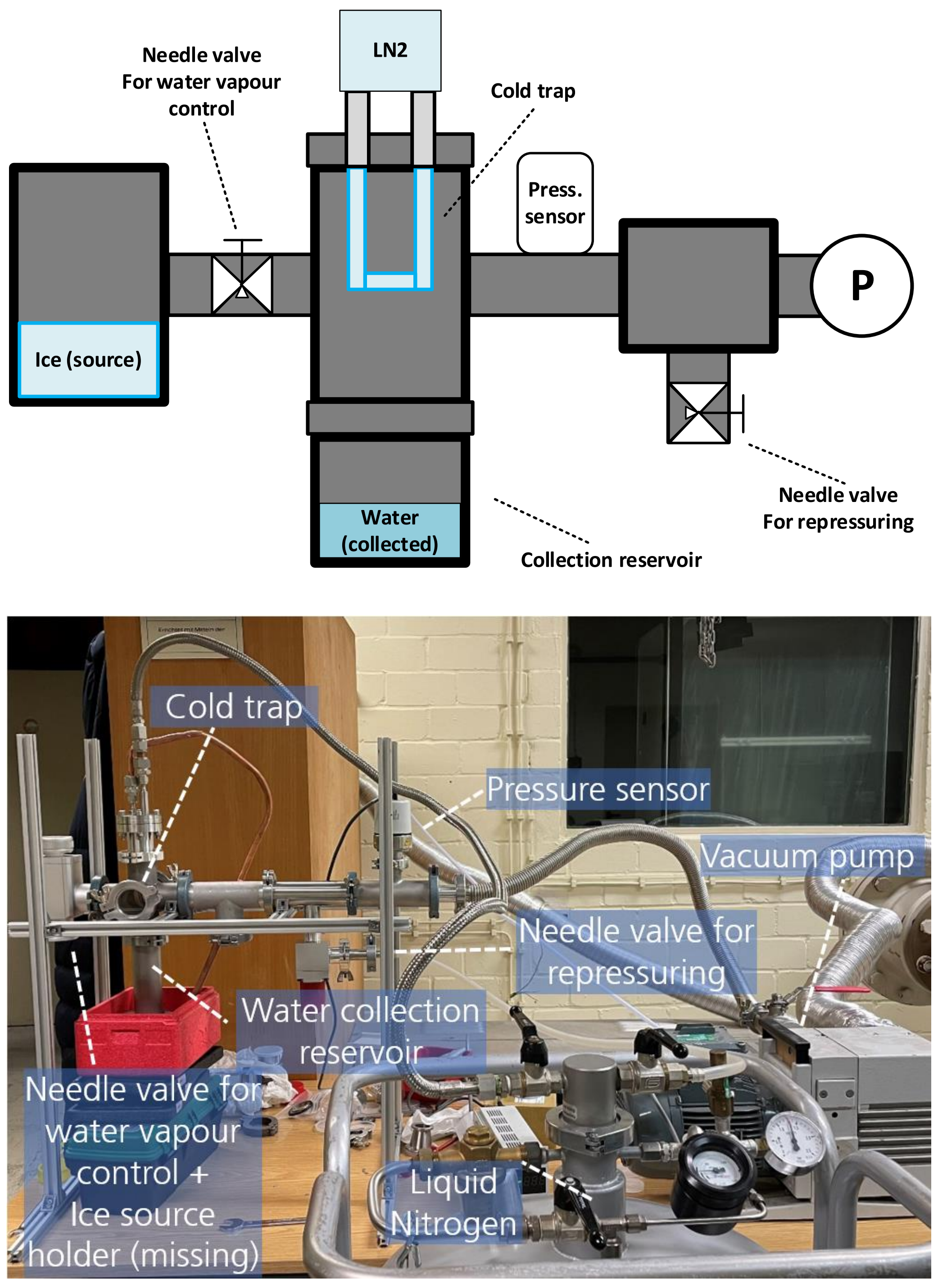


Figure 6: Schematic experiment setup above and the actual setup below.

The experiment was designed to test the effectiveness of the cold trap when the vacuum pump is running ("constant" low pressure). This would be analogous to the cold trap being exposed to the ''atmosphere'' of the Moon. In table 1 the results are presented.

Table 1: Results of the cold trap experiment under low pressure.

Run #	Sublimated [g]	Captured [g]	Efficiency
1	9.34	7.11	76.12%
2	4.45	3.18	71.46%

Figure 7: Cold trap without ice (left) and with ice (right).

Secondary to this, experience and insights were gained along the way about cold traps and working with these test setups.

The collection efficiency was surprisingly high, despite the shape of the cold trap not being optimized.

5. Conclusion

The challenge of this research project is the lack of data and previous research done in the field of water capture for ISRU. Nevertheless, these outcomes provide a solid foundation for LUWEX and future research. Many different ways to capture water vapour are envisioned, and this work provides an initial overview in some of the possibilities. Future works will investigate what the most optimal way to capture water would be for different scenarios.

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

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 program of the European Union with the grant number 101081937.

Funded by the European Union