A NEW WATER EXTRACTION METHOD TO GENERATE AND CONTROL WATER RESERVOIR IN PLANETARY ENVIRONMENTS.

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Introduction: Water extraction in planetary environments is an unresolved problem of both basic science and technical nature. No practical solution for this process has yet been established [1], although it is sure that universal solution does not exists, as it is a multivariable problem. Here, we present a new patented method for water extraction from icy regolith [2], which targets primarily water ice deposits on the Moon and Mars.

Method: The idea of this invention strongly focuses on means to obtain a stable and desirable phase change of water ice by controlled generation of a water reservoir and subsequent production of water. Reservoir is controlled through thermodynamic and technical parameters of temperature, pressure and production. This method draws from Enhanced Oil Recovery techniques used in petroleum industry and may be used for both in situ and ex situ extraction of water in planetary environments (environments of low pressure, low temperature and low gravity). The aim of this invention is to increase recoverability of water and ensure minimal losses of heat, mass and equipment.

The primary characteristics of the method and device (Figure 1) is use of a buffer gas injected into icy regolith or ice deposit before, during or after heating in a controlled process, with desired outcome understood as generation of a liquid water reservoir, out of which water may be produced for storage and utilization. With in situ considerations, this method relies on use of at least one drilled and completed production well equipped with a heating device and pump. The closest analogy to this process is Rodwell [3], although medium enabling liquid water production is not recirculated hot water but buffer gas.

Buffer gas guides phase change through the desired path of melting, which has substantially lower energy requirements than sublimation (with latent heat of fusion of 333.5 $kJkg^{-1}$ and latent heat of sublimation of 2,838 $kJkg^{-1}$). Its second role is to enhance convective heat transfer, rendering in situ or ex situ heating more efficient, thus lowering energy requirements for heating or making the process faster.

Choice of buffer gas depends on location of extraction operations but in general it should preferably have a lower freezing and higher condensation point than water vapour. The gas may be sourced in situ (like atmospheric CO_2 on Mars) or brought from Earth. With use of separation system, buffer gas may be reintroduced to the system, however its recycle rate depends on mass losses due to regolith permeability.

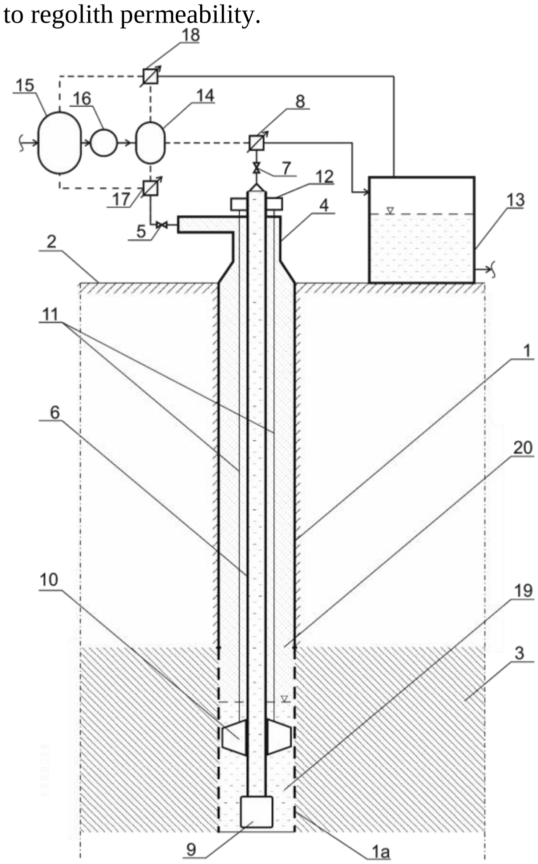

Figure 1. Patented in situ water extractor. Annotations description available on request.

Heating efficiency: Series of experiments have proven that even small increase of pressure during regolith heating makes the process faster and easier to control because convective heat transfer starts becoming dominant [4]. An example of heating differences at pressure difference of 3.6 Torr is shown in Figure 2. It infers primarily that (a) with lower pressure heating was harder to maintain at the set point of 100 ^{o}C, and (b) with higher pressure heating was roughly 3 times faster 2 cm from the heater and 6 times faster 4 cm from the heater. Similar trend is expected to be seen in cryo-cooled icy regoliths, which is a subject of further research. The cardrige heating source used in experiments was placed at the center point of 2.5x3.8 inch cylinder sample filled with air-dry JSC-1A regolith and sourced with 30 V DC current to obtain power of 5 W.

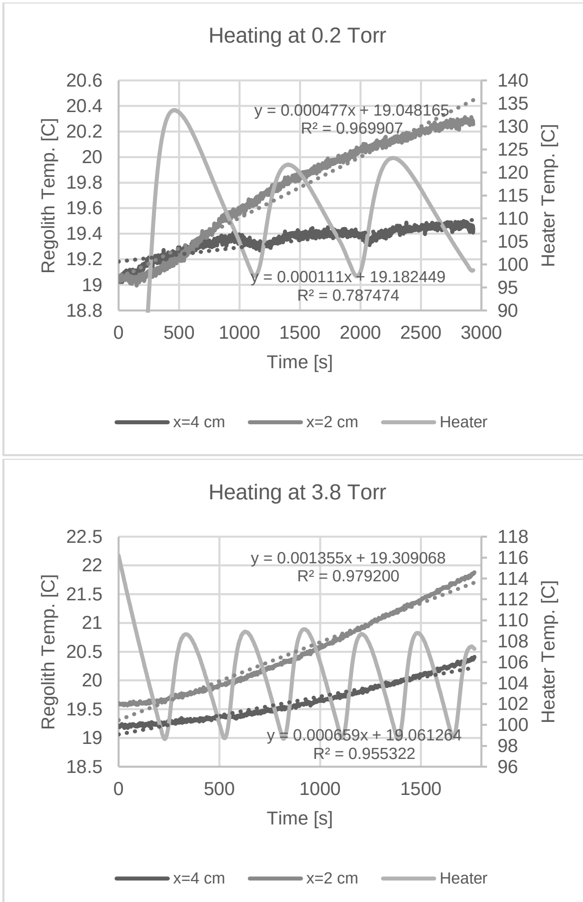

Figure 2. Heating rate of air-dry JSC-1A regolith at 0.2 (upper plot) and 3.8 Torrs (lower plot).

Reservoir generation: Although water resources in extraterrestrial environments usually consist of water ice deposits, water reservoirs may be generated artificially during extraction processes either as vapour or liquid reservoirs within subsurface or within ex situ processors. That said, reservoirs in extraterrestrial environments may be engineered to properly achieve water extraction project's objectives (e.g. water production rate) and minimize risks.

In general, artificial water reservoirs are bounded by phase change interface, which is a dynamic condition, especially in porous space . Based on environmental and engineered thermodynamical properties, there may be many phase change interfaces within the same reservoir (ice-vapour, ice-liquid, liquid-vapour). The overarching idea of generation and control of a reservoir is to maintain phase change at the least complicated, most stable and desired path on a water phase diagram, that guarantees lowest heat, mass and equipment losses and highest production rates.

The desired phase change in the patented method is water ice melting, however locally it may result in ice sublimation and even liquid evaporation.

It is not clear, which set of pressure, temperature and water production rate in a certain set of regolith and environmental properties would result in most optimal and stable phase change. Experimental research and ground-truth would provide relevant data that would be used in resource evaluation and technology development.

Methods comparison: Using mass balance, water extraction processes can be described via differential equations [5]. In case of this method, it is:

$$\frac{dm}{dt} = M_{gas} - M_{gas.back} + M_{fusion} - M_{water.pump} - M_{gas.loss} - M_{water.loss}$$

This equation solves change of mass within reservoir during water extraction process.

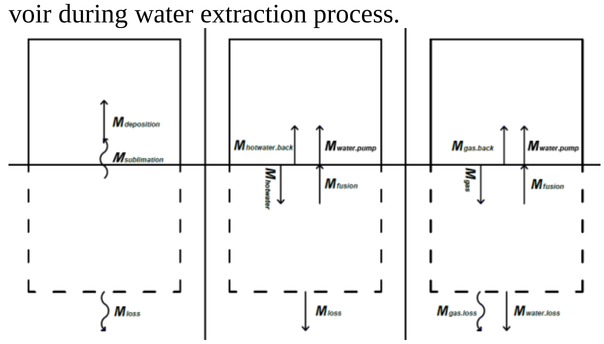

Figure 3. Viable methods for water extraction. Sublimation (left), Rodwell (middle), this patent (right). Upper parts of figure stand for closed system (i.e. installation), lower parts stand for open system (e.g. subsurface).

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