Prospective Study: Harvesting Solar Wind Material via Non-PSR Lunar Regolith

H. L. Hanks, No Affiliation, 1820 El Mar Lane, Seabrook, TX 77586, helen.hanks@zoho.com

Abstract

A literature review was performed to investigate the possible creation of water on the Moon by solar wind interaction with lunar regolith. A maximum of 1.6 x 10^7 kg.yr-1 could theoretically be produced on the Moon by this interaction. The actual rates of production and retention are significantly less and are determined by reaction kinetics and diffusion, both of which are strongly determined by temperature. Studies show that the maximum yield of hydroxyl production (and hence possible water production) occurs at lunar noon when the temperatures are highest and the flux of protons is highest [1].

There is evidence that diurnal movement of water molecules occurs from the equatorial regions to polar perennially shadowed regions [2]. Simulations also show that a portion of the water molecules may diffuse downwards into the subsurface [1] [3]. Data from the Apollo heat flow experiments show there is a steady temperature of approx. -21 °C at a depth of 1.3 m combined with a sharp increase in thermal conductivity a few cm down [4]. Once molecules diffuse down that far they are effectively in a perennially shadowed cold trap – at least until disturbed by lunar gardening processes.

The data found in literature were then used to design a device for harvesting this water and other volatiles. The solar wind activated material process (SWAMP) module uses concentrated solar or radio thermal heat to release adsorbed volatiles (including water) from lunar regolith and separate them.

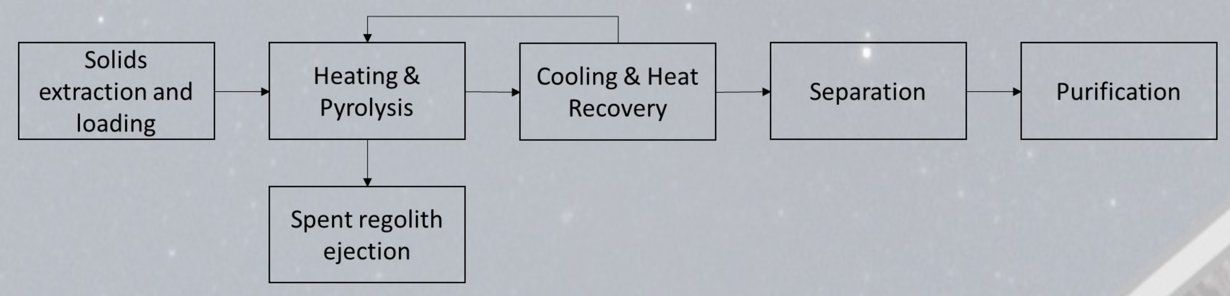
The Case for Mining Non-PSRs

Although higher concentrations of hydroxyls have been detected in the polar PSRs, there is an operational argument for attempting to harvest more moderate amounts of water from non-PSR regions, as it can be achieved in a safer, more convenient and more autonomous fashion.

PSRs	Non-PSRs
1% of lunar surface, restricts missions that can be combined	99% of lunar surface, operation can be aligned with other mission goals
Never naturally illuminated	Naturally illuminated diurnally
Temperature ~ absolute zero	Temperature -178 °C to + 117 °C
Terrain less well known terrain with steep gradients	Large areas of flat, well mapped terrain available
Regolith particles likely frozen together, making it harder to extract	Regolith dry enough to flow smoothly, easier to extract
No line of sight for remote operation or communications	Line of sight from surface for remote operation and communications

Engineering Requirements

A batch process which will contain with an airtight seal and heat up lunar regolith to 700 °C. This process will then extract volatile gases from the sealed chamber, recover heat to use for the next batch, separate and purify the volatile gases.



The device should be designed for:

- Continuous outdoor operation on the Moon including radiation risk, micro-bombardment and extreme temperatures
- Choice of concentrated solar or radio-thermal generator heat sources
- Easy connection via a standard port that will allow a hose from another regolith-heating process to be attached
- Machine should be easily operable and troubleshooting should be possible in a space suit
- Remote autonomous operation mode required as many very small batches of volatiles will be collected.

Engineering Feasibility

Considering a hypothetical kilogram of sub-surface lunar regolith heated from 0 °C to 700 °C in a sealed box with no headspace gives an idea of the energy inputs required to obtain water and other highly volatile compounds [5] [6].

Technical Data for Hypothetical 1kg Regolith	
Bulk volume	667 cm^3
Void volume	267 cm^3
Energy to heat from -20 °C to 700 °C	~513 kJ ~143 W-H
Heat time with 1 m^2 solar heat array	~15 mins
Gas pressure generated	~8 barg
Water quantity generated	~0.27 g
CO2 quantity generated	~0.51 g

This energy input requirement can be drastically reduced by taking advantage of heat integration and process integration opportunities.

Process Integration

The heat load required for this process can be reduced drastically by using internal heat integration: intelligently designing the sequence of fluid and regolith movements so that hot spent regolith is used to partially heat up incoming cold regolith.

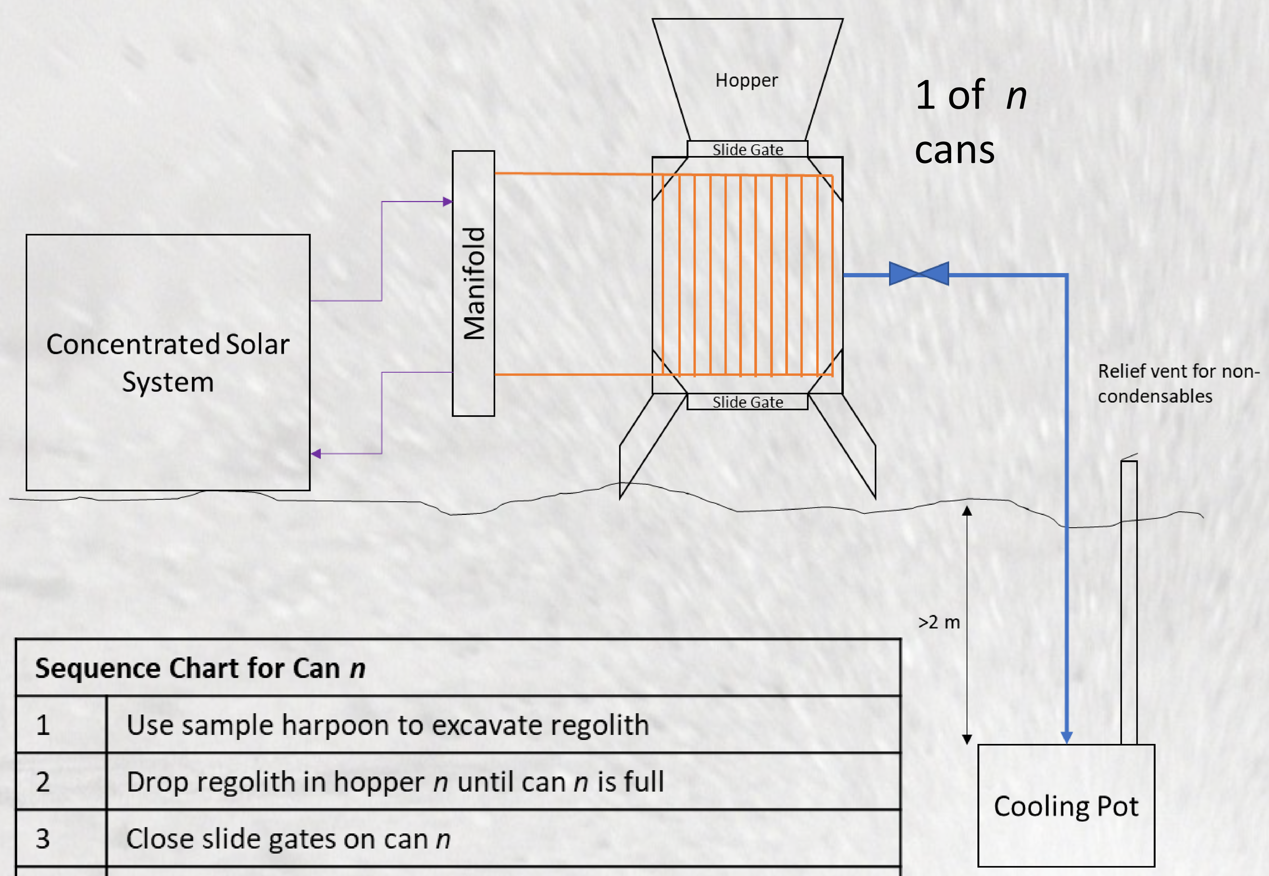
It is also possible to integrate the process with its surroundings – for example by using the hot surface temperatures to help heat up regolith and using the cold underground temperatures to help liquefy the water product.

Finally, the process can be integrated with other processes that are complementary. As exploration and settlement on the Moon progresses, there will be a variety of processes taking place that involve heating and in some cases melting or sintering lunar regolith. It would be advantageous to collect the volatiles released during these processes using a standardised port design. Releasing the standard for this port early increases the chance of adoption by other lunar ISRU processes.

Potential complementary processes include:

- 3D printing buildings and other structures
- Glass smelting
- Metals and extraction
- Oxygen extraction

Design Concept



Sequence Chart for Can *n*	
1	Use sample harpoon to excavate regolith
2	Drop regolith in hopper *n* until can *n* is full
3	Close slide gates on can *n*
4	Equalise temperature between can *n* and can *n-1* via internal coils
5	Run concentrated solar fluid through coil in can *n* until target temperature reached
6	Equalise temperature with can *n+1* via internal coils
7	Eject regolith from can *n*, open valve, send volatiles through ground cooling to storage

Note: Heat recovery is increasingly efficient as number of cans and number of equalisation steps increases

References:

[1] Grumpe, A. et al (2019) Icarus 321, pp. 486–507 [2] Livengood, T. A. et al (2015) Icarus 255, pp. 100–115 [3] Farrell, W. M. et al (2015) 255, pp. 116–126 [4] Langseth, M. G. and Keihm, S. J. (1974) https://ntrs.nasa.gov/search.jsp?R=19750006612 [5] Gibson, E. K. and Johnson, S. M. (1971) LPSC2 pp. 1351–1366 [6] Grant, H. et al (1991) Lunar Sourcebook

Background image: NASA Goddard Conceptual Image of LADEE https://www.nasa.gov/sites/default/files/thumbnails/image/ladee_web.jpg