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MAIN SYSTEM ELECTROLYSIS AND PURIFICATION FOR A LUNAR ROVER TEST FOR EFFECT ON WATER CONTENT

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Abstract

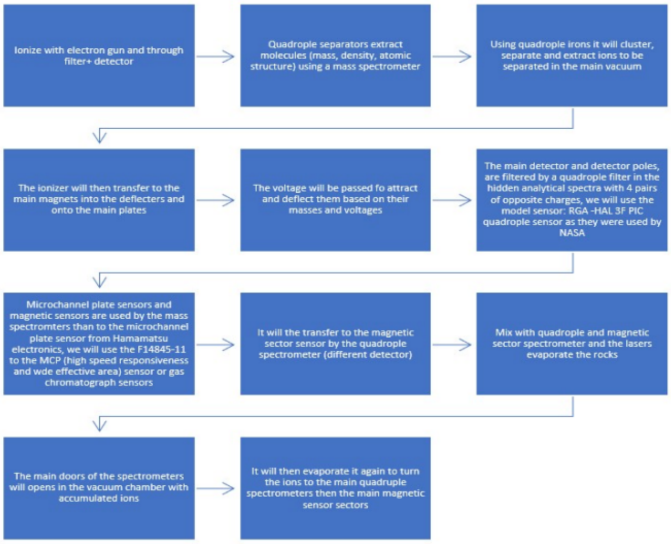
Water, one of the most important ingredients of life, is present in abundance on the moon's surface. Previous lunar missions like the Apollo Program, Chang'e 1 and Chandrayaan mission have suggested that there is water present on the moon. Although it was believed that water can exist only on the far side of the moon, recent findings by NASA's SOFIA suggest that water can exist even on the sunlit side of the moon. Our paper proposes a sixty kilogram rover proven by preliminary studies at the Wiechert crater in search of water or water ice, extracting and lastly purifying it. This is significant since these ingredients can also be for future human settlers as well to develop economic prosperity and ensure commercial mining of water resources for electrolysis fuel cells. The main payload of this mission is the purification systems and the rocket fuel generator (electrolysis cell) for the moon. The reason why this payload is chosen is because these are 100% INSITU resources and can be drilled from the regolith. This is going to be working when the spectrometer and the hyperspectral imagers are going to be prospecting. The lunar surface. Once the possible chance of water has been found the drill is going to be extracting the water by heating the volatiles in the drill. We will then purify the water by using a hydrogen reduction and ammonia as a scrubber method and scrubbers to remove excess gases from the vapour purifying it from ilmenites and basalts. Then the water will go to the electrolysis cell for further extraction and then for rocket fuel with the help of separating the H from the O. The next science payload is the mass spectrometer which is going to be using a mass magnetic sector and a quadrupole mass spectrometer to separate the ions and the compounds which will then go to the detectors which are both GC or a gas chromatograph. These are going to be working when the lasers have melted the rocks for the gas to come out to be analysed by the electron gun and onto the filters of the RF iron beams and the magnets for separation and then onto the main detector. This type of spectrometer has never been used before since its using a quadruple and a magnetic sector mass spectrometer. These instruments and payloads are all technology demonstrations.

Introduction - Concept of Operation

The main concept of operations for the Wasp Lunar Rover to operate are:

1. The rover will find suitable landing spots using the TRN system and algorithm along with the cameras on the entry descent landing craft. Once the landing spot is confirmed the rover can descend and go to the location desired.
2. The rover will begin its mission at 84 degrees South East of the Wiechert crater. Once it has deployed its components and sent signals to the nearby communications on Earth for double system-checks, it will begin its journey in search of water. It will use its TRN algorithm and navigation cameras to locate possible extraction points on the Wiechert crater for icy-bound or water-bound regolith.
3. The rover will be in contact with the Earth using the relay satellites on the moon like the LRO (lunar reconnaissance orbiter) and lunar flashlight for example. This will be done with the S and the X band antenna systems. We are using the LRO because the antenna sometimes cannot get a complete field of view of Earth and hence the disruptions in the communication can cause the rover to not get complete and vital information.
4. Our speculated mission duration will be 14 days.
5. The rover will start moving and testing out the various systems like the robotic arm, mobility, and the sensors on the rover to verify everything is working perfectly on the moon.
6. The sensors will once again confirm the areas of water using the instruments like cameras, hyperspectral
7. imagers, and mass spectrometers.

8. Once the rover is in the targeted area the rover will collect and vaporise the samples for the mass spectrometers to study the lunar regolith. The drills can start drilling and collecting samples for extraction of volatiles. The drill and the robotic arm will collect samples.
9. The process of drilling should be monitored using sensors to measure the depth using LIDARS. The drills will be using springs as well. The cameras will monitor and use differential algorithms to determine the depth of the drill.
10. Due to the size of the drill, no sensors will be added to the bottom of it.
11. After the regolith is collected using an advanced purification mechanism the unwanted material will be refined and removed from the regolith sample for ease of water extraction using hydrogen reduction. This is going to be done when the heaters are inside the drill. The water will evaporate. Once the water has evaporated the volatiles and water will be vaporised and collected to be condensed at a certain pressure and temperature. After this, the collected ice will be water.
12. We will then start to use electrolysis to use the hydrogen for testing potential fuel for rockets and oxygen for the astronauts. (the water will be checked using the sensors like the spectroscopes and imagers in various spectrums)
13. The drill will check and complete the collection process. After this, the arm will retract and then go back into the rover.
14. The process will repeat and the purification and other discoveries can be done and made. The database is going to be the same which is using the TRN algorithm system.
15. The rover is going to be only operating on the lunar day. We will be putting the rover in hibernation. We hope that the rover will communicate with Earth in the morning .



Regolith Analysis

Why the Petrographic Analysis of Regolith

The petrographic analysis will help determine the structural physics and chemical composition behind the regolith to identify how it will be constructed before the process of MSEP (i.e. the electrolysis and purification capabilities). So that the rover is capable of operation. These will be the expected compositions and readings of the excavated regolith analysis:

Chemical Composition of Lunar Regolith

Note that when regolith or mineral rock is crushed; it will be difficult to identify the original mineral and chemical composition of minerals in size less than 60 micrometres. If crushed using the drill.

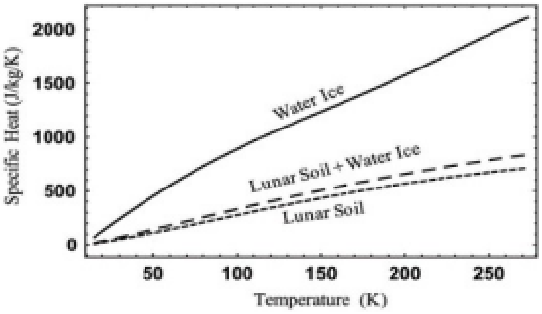


Fig. Thermal conductivity of water ice, lunar soil, and 8.9% by weight water ice in lunar soil.
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Elemental and Chemical Composition Locations

Basalts

Mare basalts are composed mainly of clinopyroxene (type of magnesium-iron-calcium silicates common in basalts), but all also contain plagioclase (calcium-sodium alumino-silicate) and ilmenite (iron(II)-titanium oxide), and some contain olivine (magnesium-iron (II) silicate; common on Earth and Moon).

Mare Tranquilitatis is the landing site of the Apollo 11 mission where mineral rock analysis was done, it is located 400m west of the west crater and 20km south-southwest of the crater Sabine D. The results of mineral analysis of lunar rocks resulted in a fine gradient in crystallisation at 40-100 micrometres. They were abundant and most rocks were identified to be basaltic due to their high concentrations in titanium.

However, at Apollo 15 (landing site is at east longitudes 3 degrees 39' 30'' and north 26 degrees 4' 54" of the Apennine mountain range) and the Apollo 12 (landing site is southeast of the Ocean of storms) low titanium concentrations were found.

In the Luna 24 sample collections (landing site is Mare Cirsium) there were coarse grained basalts in crystallised sizes of 100-500 micrometres. Concluding that the Mare Cirsium has more monomineralic particles than the Apollo 11 , but both have the same concentrations per area.

These basalts were also composed of pyroxene and magnesium grains prevalent in the Apollo 15 grains. Very low basalt concentrations were present in the Apollo 16 landing site collections (Descartes Crater), in variation there was a negative variation between monomineralic plagioclase grains, crystalline matrix breccias (a porous substance) and glass.

Basalt grain density and porosity

High titanium concentrated basalts show more density (3.42-3.46 g.cm-3) than low titanium concentrated basalts such as (12051, 12052, 15555 and 15556 as named by the data). The low titanium basalts showed a prevalent amount of other substances such as Al_2O_3 and MgO.

Porosity was less than approximately 10 percent for all the regolith samples, but lunar sample 15556 (collected from Apollo 15) had an anomaly of high porosity 26% as it had more cavities (vesicles) than the other rocks.

Lunar Breccias

Size (um) Wt.%	250-500 11.91	150-250 13.13	90-150 15.99	75-90 50.48	45-75 14.45	20-45 17.37
Breccias	5.7	6.1	4.9	5.6	6.2	4.7
Vitric	(4.4)	(5.8)	(4.6)	(3.4)	(5.6)	(4.4)
Dark Matrix	4.4	5.5	4.3	3.4	4.7	4.1
Light Matrix	--	0.3	0.3	--	0.9	0.3
Crystalline	(1.3)	(0.3)	(0.3)	(2.2)	(0.6)	(0.3)
Poikilitic	--	--	--	--	--	--
Melt Matrix 1.3	1.3	--	--	1.9	0.6	0.3
Other	--	0.3	0.3	0.3	---	--

The Lunar Soil Sample 15601 was collected from the mission Apollo 15 and was sampled 20 metres from the edge of Hadley Rille.

The concentrations of breccia differ between locations on the moon topographically. In the Apollo 11 collected samples they had 60% agglutinates and 20% dark-matrix.

Impact-melt Breccias density and porosity

In samples such as 14310, 61016 (east rim of Plum Crater - Apollo 16), 64435, 66095 and 73255, grain densities are in the range of 2.85-2.99 g.cm-3. Per analysis, higher than the average grain density of impact-melt breccias 2.82-2.85 g.cm-3. Their porosities are dependent on the impact scenarios but in mean results they are of 20 percent porous.

Glass

Fine Lunar regolith have fractions of glasses from two repositories which are the non-crystalline material in "basaltic rocks" and the glassy bonding material found in breccias. These impact glasses are approximately 3-5% of glass and are produced from melted exotic regolith. This shows that they were mixtures of different pre-existing rock types and not original or one rock type. These objects could have also been formed from the bombardment of their heterogeneous substances on the exposure of other regolith. These impacts are more miniscule in size than the glass beads.

Ropy glasses are glasses found as broken pieces within fine dusty soil grains through cooling and crystallisation from the glass. Through studies they were found to be products of smaller impacts forming large melt sheets on the glassy impact bombs of the Ries Crater.

We will also purify and test the concentrations of the following materials present on lunar regolith:

1. Silicon
2. Solar Wind Gases
3. Calcium
4. Agglutinates

Agglutinates were formed from meteorite impacts resulting in impact melting of several heterogeneous glasses.

Strength Tests and Compression

Heat compression threshold for the Porous Lunar Regolith

Porosity in terms of the volume of the regolith will play a role in the void fraction of being pressured into the tubes. This will allow it to be easier to transport the regolith mixture through the tubes. The thermal compression will be dependent on the compressive strength of the compressors. The compressive distribution will be at a 150-degree Celsius compression at which the density was controlled in respect to the theoretical density in ranges from 99.00 ±0.5% and 92±2% (Thomas Guiltier and Amit Bandyopadhyahi, 2015).

Another useful strategy being used aboard compressing the material; allowing the thermal gradient to be decreased. Meaning, decreasing the area and length as well as decreasing temperatures at a drastic scale.

Structural Physics Background and the need for Pressure Valves

Rotational effects (of the compressor) are solely responsive from the coordination of the frame of rotations on Earth. For example, the atmosphere and the ocean both experience constant pressures along and not vertically high to low pressures. This is significant as through a process such as welding from compression (I.e. using compressed air tools or air/arc gouging). Which tested the connection between the rotation and the compression, in this experiment a disc was used in materials such as methane. The results were that the radial motion affected the temperature difference (which was owed) and the material attempted to expand.

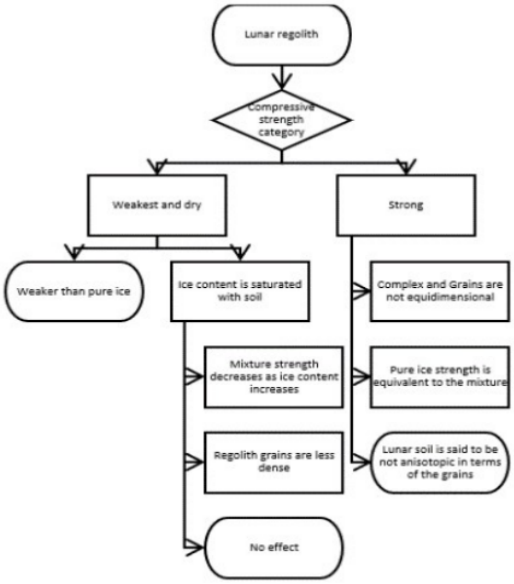
However, stresses still exist such as the plane stress where the material is under the axes or stress vector is zero. To neglect these stresses, we must change force vectors and the equations:

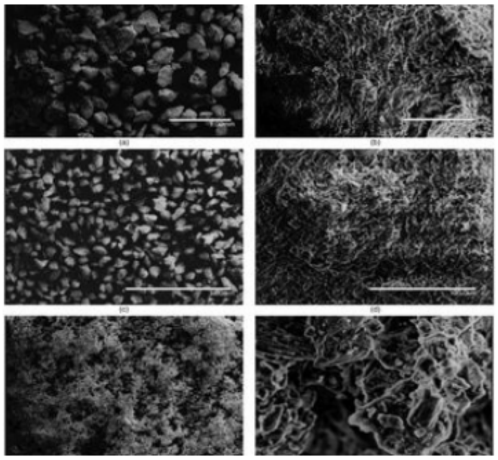
$$\frac{ds}{dr} = \frac{1}{E}(\sigma_r - v\sigma_H + E\alpha T)$$

$$\frac{s}{r} = \frac{1}{E}(\sigma_H - v\sigma_r + E\alpha T)$$

Where:
E = *Young’s Modulous*
T = *temperature*
σ = *Tensile Stress* (force per unit area)
v = *Poisson’s ratio* (deformation or expansion in a material in perpendicular to the direction of loading)

Icy-Bound and Water-Bound Regolith Strength





The grains are saturated with water due to testing and the water concentration average is equal to the porosity of the dry regolith (46% in volume at 0-60cm, in ranges of 19% of the mass of this regolith would be water ice and increases when depth increases). The density of solidified lunar regolith is 3.1g/cm^3 and the water ice collected is 0.92g/cm^3. Through these samples we predict that the Lunar Prospector would measure the ice content the averages would be 10% of mass and that there would be a layer of dry and weak regolith covering the ice.

Testing Site - Wiechert Site

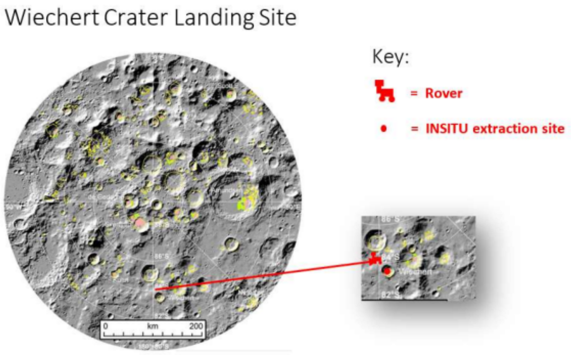


Fig. Map of the Wiechert Crater and Our Rover

For the rover landing site, we propose to land 84 degrees South of the Wiechert crater as surface ice has been mapped on that location on the moon and has been classified as a PSR. This will be our starting location and through the TRN algorithms it will locate an exact extraction site (for water ice in regolith) within the crater. It is estimated that it has 1.545 x 10^12 grams of water ice as per the LCROSS experiment. Once the TRN extracts the location for the excavation of the regolith the communication bands will send signals to the nearby Lunar gateway and inform them of the regolith excavation trajectory.

Impact Crater Elemental Composition Conclusion

We chose this location as it is a permanently shadowed region meaning that concentrations of ice are up to 30 wt%. Another advantage as through test samples considered in the following pages the compressive strength is quite low meaning that its porosity and density are low as well. This in conclusion eases the rate of vaporization of lunar ice whether amorphous or crystalline. Through analysis of the Charon using an infrared spectrometer; temperatures never exceed 80 kelvin and are in ranges of 35 to 50 kelvin meaning that crystalline ice is most deposited.

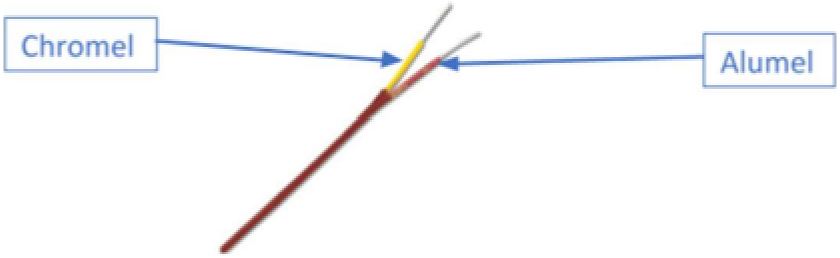
Main System Electrolysis and Purification

NASA has identified that the correct place for landing and using critical extraction methods of water purification was near lunar poles and near-permanently shadowed regions (PSRs). Our research has also identified that to extract efficient water concentrations our rover will land near icy regolith to the superficial heterogenous mixtures of breccias and basalts. We have also identified that extraction of water near frequent meteor collision areas is a suitable place to extract water as glassy regolith is formed near them with percentages of ice concentrations from 0 to 11% as per the JSC lunar simulant. LCROSS indicated water concentrations in the range of 5.6 + 2.9% and of porous regolith.

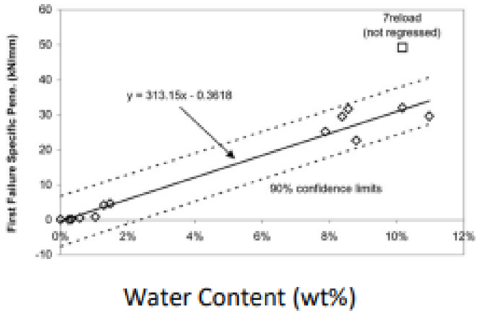
9.1 Test for effect on Water Content Due to meteorite collisions and Regolith Strength

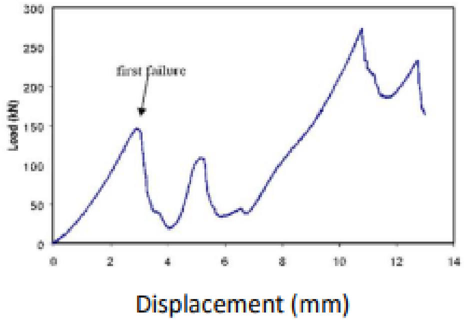
To measure material load-penetrations the regolith-sample encountered and its effects in the ice and water concentrations such as temperatures, we will start testing the mixtures as homogeneous by adding water. Compression at 10.9 cm of diameter using stainless steel test rings will be used at a force of 467 kN (simulating meteorite lunar collision compression by adding a force). Then placing the sample to cool it down in liquid nitrogen at negative 196 degrees Celsius. These temperatures will be measured consistently making sure they were at constants so no new products would be formed using the type K thermocouple.

Type K Thermocouples are temperature sensors that can immerse, be placed at the surface or as a wire for a sensor or cable. They can measure temperatures from -270 to 1260 degrees Celsius and in addition are quite the revamp for accuracy and inexpensiveness. We propose to use them as they can withstand the fluctuating temperatures of the moon. Using an electro-hydraulic closed loop; plates were used to compress the sample by using a 19mm diameter hemispherical indenter at 1.24mm/sec.



This melted the intergranular ice of the regolith sample .There was a failure as shown in this figure in which its impact on lunar regolith changes it from porous and ductile to brittle and weak behaviours. These failures may be the failures of electrohydraulic servo powered loops. They could also be due to the saturation of the sample in terms of ice concentrations.





Spectroscopic results showed presence of hydroxyl and water absorptions. Thermal processes collect water containing regolith or somewhat ice concentrate are heated and water evaporates. If the mixture of regolith and ice is present (icy regolith); this is due to excessive heating in physical processes. In bound water, heat addition breaks bonds of hydration between water substances and other substances attached in the lunar regolith (mentioned in the regolith analysis). The substances in the regolith that bond are released as products.

Bound water requires higher excessive heat than icy water as less bonds are broken. Regolith bound water or icy regolith mixtures are formed due to the present diffusivity of regolith and external gases and their modes. For icy regolith we will insert more inert gases for easier compression and heating and removing the particles diffused out of water. For instance, the diffusivity of potassium is 7.7cm2/s and for helium and argon it is 2.3.We will identify the classification of the regolith by using high-spectrum spectrometers. This test summarises the differences in the material and concludes the variables that need to be assisted within the purification process.

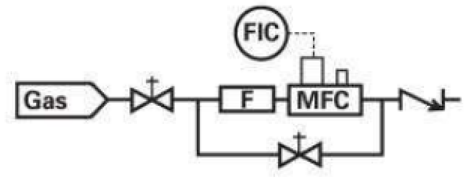
Tubular reactors are where a given quantity of lunar regolith is placed inside to heat the regolith from the reactor walls in continuous flow. We will use tubular reactors from the Parr instrument company offering two-phase flow in counter-current flows attached to a catalytic bed material for our heterogeneous reaction. During pre-heating of the regolith, it will maintain the reagent to be collided with the wall. In terms of efficiency, the system allows for adjustable features. Our tubular reactors are scaled down at an internal diameter of 20cm and a length at 35cm. For backup systems to avoid harmful catalytic dust we will vent operations in dry atmospheres.

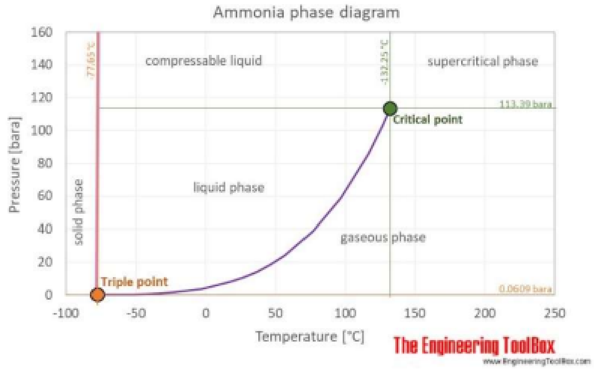
We will be using ammonia as a scrubber and water polisher to contain and filter the water in the purification systems before regolith compression. Ammonia will be stored in the purge line which will include a shut-off valve, filter, metering valve and a back-flow/double check valve*. For redundancy we will have duplicates of each valve.

- Shut off valves: for managing compressed air in pneumatic applications

- Filter: reducing containment in purge air
- Metering Valve: For accurate flow rates of gases
- Back-Flow/Double Check Valves:(5, 3 for our systems, electrolysis and purification, and 2 for redundancy):
- Protects the purge line from the backflow of pressure as a casing, will be use to transfer hydrogen to the main hydrogen storage tank and one for oxygen transfer to the oxygen storage tank. We will also use it to transfer excess gases of purification and evaporation of icy vapours

To measure gas flow, we will be using an electronic Mass Flow Controller for measuring ammonia gas at maximum operating pressures at set heater temperatures.





We will use the mass-flow controllers from the MKS company due to its light-weight and high durability as well as low power consumption rates.

- Control Range2% to 100% of Full Scale
- Full Scale Flow Range5 to 50,000 scm • Seal Material Viton, Buna-N, EPDM, Kalrez or Neoprene
- Flow Input Output Signal Voltage: (0 to 5 VDC) 15 pin Type "D" male, 9 pin Type "D" male, Current: (4 to 20 mA) 15 pin Type "D" male
- Maximum Inlet Pressure150 psig
- Normal Operating Pressure Differential10 to 5000 sccm; 10 to 40 psid, 10000 to 20000 sccm; 15 to 40 psid, 30000 to 50000 sccm; 25 to 40 psid
- Proof Pressure1000 psig
- Burst Pressure1500 psig
- Typical Accuracy± 1% of set point for 20 to 100% Full Scale, ± 0.2% of Full Scale for 2 to 20% Full Scale
- Repeatability± 0.3% of Reading
- Resolution 0.1% of Full Scale
- Zero Temperature Coefficient< 0.05% of Full Scale/°C
- Span Temperature Coefficient< 0.08% of Reading/°C

Gas/liquid separators will ensure that condensed water vapour from the regolith will be collected and condensed in the top of the vessel using a cold finger. We will also use control and data acquisition sensors for controlling the systems mentioned above using a computer-based model. They will also ensure that through the ventilation system exposure to the minimal concentrations of different gases on the moon and the unwanted gases will not be extracted. They are also responsible for separating the scrubber ammonia from the systems.

Purification of water from Ilmenites (titanium and basalt)

Hydrogen reduction as proposed by RESOLVE will aim at finding iron oxides in ilmenite or sometimes the glassy bonding material in breccias. The reaction will involve iron dioxide and water. We Will be using a cold trap and Paragon’s Nafion-based Ionomembrane Water (in the image) for purification to measure the containment filtration percentage in the figure below.

For micro-printed heating we will use heaters from MINCO technologies which can withstand temperatures in ranges of -200°C to 200 °C. It will be made of Kapton and is specifically a polyimide thermofoil heater* as the best material for transferring heat to the regolith to evaporate the water vapour . We are using these heaters as they have an approval by NASA, were used since the Mercury program, and were included(as the only suppliers) on NASA’s Qualified Product List.

- Aluminium Specific heat of material (J/g/°C)= 1.0, density (g/cm^3) = 2.70
- Thermal conductivity of Kapton in low temperatures= 4.638×10−3 T 0.5678 W·m−1·K−1 Material: .0.002”
- Polyimide/0.001” FEP, (0.05/0.03 mm).
- Resistance tolerance: ±10% or ±0.5 Ω, whichever is greater.
- Dielectric strength: 1000 VRMS. Minimum bend radius: 0.030” (0.8 mm). Lead wire: Red PTFE insulated, stranded

Hydrogen reduction reactor sub-systems

In the reduction of JSC-1A these variables were tested and will be used for reference for our mission.

Testing for icy regolith in tubular reactors

1. Closed reactor accumulates pressure build- up of the vapour and the constant change in water vapour Once pressure equilibrium occurs:
2. Venting i.e., exposing air to the secondary repository to the water vapour to maintain low pressures
3. Constant Time depends on evaporating surface area, resistance of regolith to vapour movement and volume

Model Analysis of our MSEP (Main System Electrolysis and Purification:

There are several variable differences in terms of the storage and transfer mass (from the regolith) of the vapour condensate in the free volume and the reactor.

The variables for our Lunar mission are as follows:

1. Tubular temperature: If temperature increases the vapour pressure will increase on the surface which increases the rate of evaporation
2. Free volume: increasing this will lead to a decrease in vapour pressures (not drastically) still allowing an increase in evaporation and allowing more excessive water vapour collection
3. Mass transfer coefficient: decreasing this variable will increase the resistance of the regolith to break bonds with the water vapour in terms of transport. This decreases evaporation (vaporisation) rates.
4. Surface area of condensate : The surface area of the condensate's reactor, if increased; will increase the room for vaporisation per unit and quantity of the icy lunar regolith.

Number density of water molecules and vapour density are found by Avogadro's Law which considers a vacuum and a non-zero pressure at the condensate surface. This also relates to the number density function yields of the icy lunar regolith

$$n_s = A\rho_s$$

Deriving Avogadro's law with the rate of change of condensed-water mass into the vacuum is written as:

$$\frac{dm}{dt} = -kS\rho_s$$

The initial mass of the condensed water and the initial density of the vapour *in free volum*e

$$\rho_r = p_0 + \frac{(m_0 - m)}{V}$$

The full equation if the mass of the condensed phase in the tubular reactor is:

$$\frac{dm}{dt} + \frac{kS}{V}m = -kS(p_s - (p_0 + \frac{m_0}{V}))$$

Equation of time constant:

$$t_c = \frac{V}{kS}$$

Evaporation During Reactor Venting:

Mass of vapour in free volume at the end of heating is $\rho_r V$ which is less than the water in the condensed surface. Though vaporisation from the condensed phase will continue in venting the reactor is still vented at a constant pressure from the backpressure of the regulator. Vapour leaves the tubular reactor and condensed water evaporates as well as the rate of vapour pressure increases to the saturation and regulated reactor pressure.

$$\frac{dm}{dt} = \frac{kS}{R_g T_r}(P_s - P_r)$$

In terms of time constant and free volume V become:

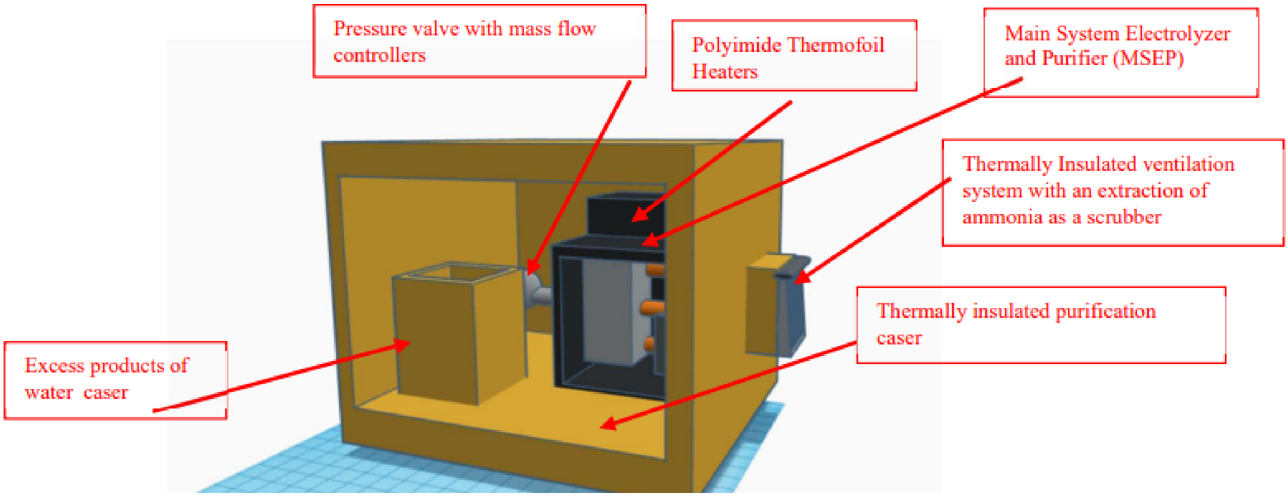
$$\frac{dm}{dt} = -\frac{V}{t_c R_g T_r}(P_s - P_r)$$

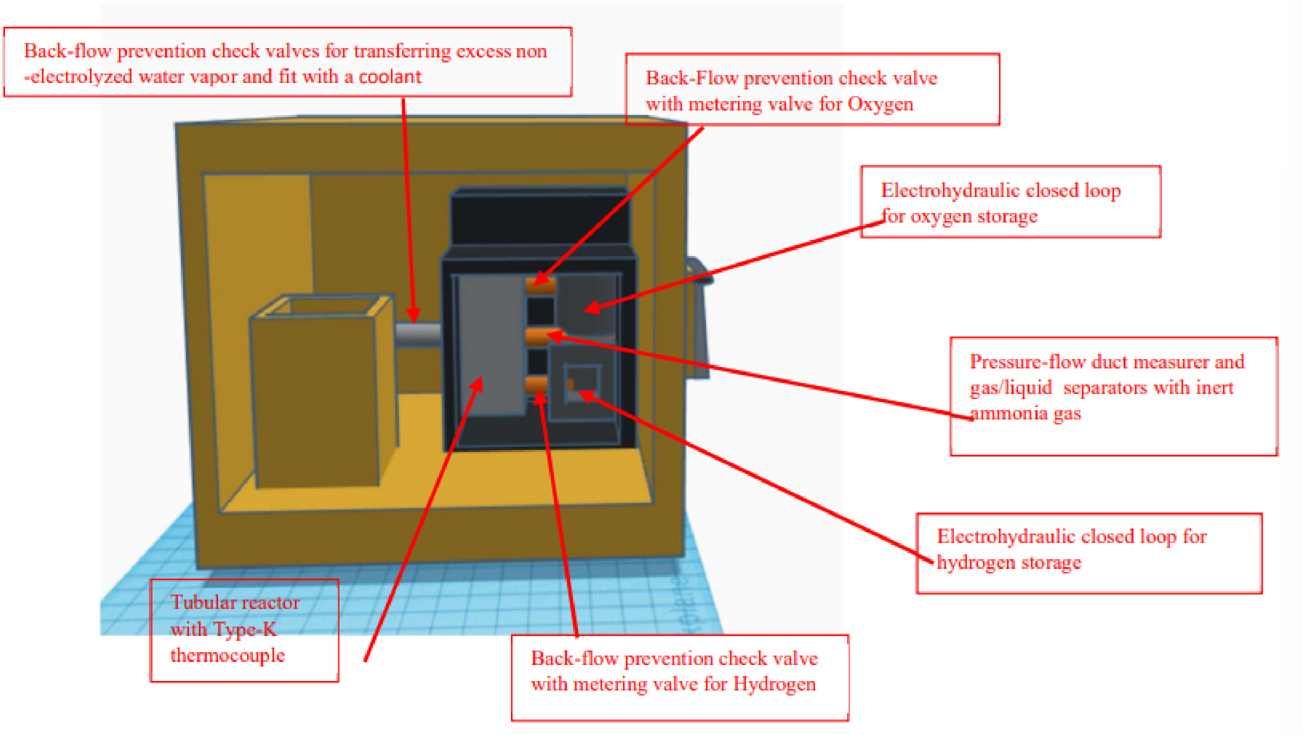
Regulated reactor pressure is relieved as . Time constant and space velocity constants during ventation the time for vaporisation *is*:

$$t_{evap} = \frac{(m_0 - m_i)}{\frac{dm}{dt}\ or\ V}$$

The distributive quantity $(m_0 - m_i)/V$ for the effective density of condensed-phase water if occupation of the free volume V was in 100kg/m3

The Diagram of the Main System Electrolysis and Purification





Fuel Cell technology Demonstration

As a demonstration for power efficiency and utilisation of lunar resources, we will utilise Rechargeable Proton Exchange Membrane Fuel Cells (PEMFC) which will use Perfluoro sulfonic acid as an electrolyzer. This will be responsible for creating hydrogen fuel from the fully purified water to both power our rover and future rocket missions. This will house an alcohol/ketone-based hydrogen storable polymer (HSP) which releases hydrogen as a product at 80 degrees Celsius. We propose to use this methodology as it is lightweight and does not require a pressurised hydrogen tank. This sheet will be attached to a catalyst layer near the anode side to increase hydrogen storage reliability per cycle.

Duty cycles and production rates:

- 20min= 20%
- 30min=33%
- 60min=51%
- 360min=96%

As the membrane we will be using a Nafion NRE-212 cell and SPP-QP gas to increase operation cycles and power generation. It is only 2mm thick and has an improved durability in terms of a lower fluoride ion release. The following reactions will take place in the anode and cathode:

- Cathode: $4e^- + 4H^+ + O_2 \rightarrow 2H_2O$
- Anode: $2H_2 \rightarrow 4H^+ + 4e^-$
- Complete Reaction: $2H_2 + O_2 \rightarrow 2H_2O$

In addition to this we will be using regenerative fuel cells using rechargeable batteries which store the water formed during the discharged reaction. Like the MER program we will be using fuel cells as well and containers to collect the end result.

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