Autonomous Mars In-Situ Resource Utilization Robot for Water Recovery Using Centrifugal Processing.

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Robotic Mission Proposal: I propose to complete a systems-level design of a multipurpose Mars resource identification, acquisition, and utilization robot and to develop a centrifugal refining process for in-situ water reclamation and storage. In-situ resource utilization (ISRU) significantly reduces the cost, mass, and risk of sustained human activities beyond Earth [1]. Furthermore, an autonomous system would free astronauts from strenuous work. A cadre of robots could be sent to Mars before the astronauts arrive to prepare a site for them [2].

Much is still to be discovered of the fundamental physics of molten metals in low gravity environments. The research objective is to design components which could provide some of the base technology eventually used on the first ISRU mission on Mars. This can be accomplished through the study of the feasibility and operability of industrial refining systems in low Martian gravity. A centrifugal furnace capable of water separation, metal melting, and spin-casting holds the most promise.

I envision a self-sufficient ISRU robot which could drive along the Martian surface scouting for rocks using computer vision driven by artificial intelligence. The AI would be informed by existing MSL data on rock composition and MRO and Odyssey data on geospatial mineral deposits. Onboard instruments similar to those on MSL such as laser spectroscopes (ChemCam) and optical cameras (NavCam and HazCam) would provide fast object determination. The robot would pick up rocks that contain hydrated minerals or scoop up icy soil. Such intelligent autonomous operations would take advantage of the local resources. With little or no human input, it would provide an astronaut team with water for drinking, conversion into fuel, and food growth. A crusher first breaks rocks and sediment into a particulates while capturing any ice or brine from scooped soil. A low-volume chemical treatment alters the pH to facilitate hydrate precipitation. Then, an electric centrifugal furnace separates metals by molecular weight via spinning. H_2O and OH gas would be collected through outlet ports. The furnace temperature would lower to cool and collect metallic resources, which could exit the chamber tangential to the spin axis. Different exit filters could extrude wire through an aperture and create powder through a diffuser nozzle. The metal could also continue to spin in the centrifuge as the furnace cools to cast a ring ingot.

Martian Soil: Mars has long been known to possess hydrated minerals on its surface. Observations of the planet's infrared reflection spectra by Carl Sagan in 1965 detected the ferric oxide mineral limonite of chemical composition $Fe_2O_3{\bullet}xH_2O$ and particle size ~25 microns [3]. Olivine basalt minerals exist on Mars [4], [5]. As such sedimentary deposits of ferric oxides age, they do not immediately precipitate into hematite Fe_2O_3, but first amorphous $Fe(OH)_3$ and then goethite, FeOOH, before becoming hematite [6], [7]. In Martian soil deposits that contain hematite, there may be additional deposits of these secondary phases which could be dehydrated to produce water reserves. Molten metal hydrolysis has also been demonstrated to produce oxygen at the anode and metals such as iron, silicon, and aluminum at the cathode [8], [9]. A multipurpose ISRU system could potentially capture both water and oxygen by refining raw Martian regolith.

Over the last decade, NASA Mars missions have adhered to the mantra "follow the water" [10]. The 2007 Phoenix Mars Scout Lander groomed soil surface with its robotic arm and found icy deposits of H_2O absorbed in the soil [11], [12]. An ISRU mission to such a region could test systems for water reclamation. Additionally, water could be present and responsible for similar soil effects in other, non-polar regions that present ISRU opportunities [13]. Production of oxygen is vital to sustained presence on Mars [1], [14]. The macroscopic and microscopic study of erosion, sintering and melting in Lunar Regolith Simulants mounted to steel places and placed near a 1000-1200 °C heat source [15], [16] provides helpful insight into methods for conducting ISRU furnace studies.

With every subsequent rover and lander sent to Mars, the mineralogy and the relative chemical composition of Martian rocks is better understood. Surface characterizations can inform the artificial intelligence system on an ISRU scout robot to acquire rocks most likely to contain desired elements. The Wet Chemistry Laboratories on Phoenix found a dominant presence of perchlorate [17]. The distribution of perchlorate salts discovered using the Surface Stereo Imager on Phoenix are concentrated in ways that, on Earth, result from the presence of thin films of liquid water [18]. A similar instrument coupled with artificial intelligence could direct an ISRU rover towards in situ deposits of liquid water.

Refining in Low Gravity: An ISRU furnace would need to maintain melting temperatures independent of ambient conditions. Refining on Earth is performed with dependence on gravity. Jigging using pulsion and suction separates minerals of different specific gravity by their relative moment [19]. Microgravity environments can support multiphase fluid flows, however flow regime geometry is altered and chaotic mixing regimes may arise [8]. Centrifugal systems have recently been developed to overcome these concerns and hold great promise for Mars ISRU.

Conclusion: ISRU research benefits science by enhancing knowledge of how to create a reliable human Mars mission and a sustainable Mars base. It deepens the modest understanding of microgravity metallurgy and will increase TRL level of many refining tools and processes. ISRU research benefits exploration by enabling mission operations that would be impossible without access to water for fuel, drinking, and radiation protection. Robotic advances in resource identification via optical and spectrographic vision will benefit Lunar and Asteroid missions as well. ISRU research benefits America's economic future by creating tools for the productive use of space. Commercial contractors could create profitable businesses by supplying a Mars station with its resources. Material caches from an ISRU refining robot could have monetary value when shipped back to Earth if they contain special raw elements.

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