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Water extraction on Mars for an expanding human colony

M. Ralphs [a,*], B. Franz [b], T. Baker [c], S. Howe [d]

[a] Utah State University, Logan, UT 84321, USA
[b] University of Southern California, Los Angeles, CA 90089, USA
[c] Idaho State University, Pocatello, ID 83201, USA
[d] Howe Industries LLC, Idaho Falls, ID 83401, USA

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ABSTRACT

In-situ water extraction is necessary for an extended human presence on Mars. This study looks at the water requirements of an expanding human colony on Mars and the general systems needed to supply that water from the martian atmosphere and regolith. The proposed combination of systems in order to supply the necessary water includes a system similar to Honeybee Robotics' Mobile In-Situ Water Extractor (MISWE) that uses convection, a system similar to MISWE but that directs microwave energy down a borehole, a greenhouse or hothouse type system, and a system similar to the Mars Atmospheric Resource Recovery System (MARRS). It is demonstrated that a large water extraction system that can take advantage of large deposits of water ice at site specific locations is necessary to keep up with the demands of a growing colony.

1. Introduction

The ability to extract and process water through in-situ resource utilization (ISRU) is necessary for a sustained human presence on Mars. This study looks at the required hardware and the related production rates that would be needed for water production for an expanding human colony on Mars. This colony would receive new colonists from Earth every two years, when the planets are positioned properly in their orbit and conditions are feasible to send a mission to Mars (A propitious alignment of planets, 2015).

Although not available in 2015, it is expected that future technology will allow for missions to Mars to carry 6, 12, and eventually 24 humans in each mission, or that multiple transports will be sent in each mission. With this assumption in mind, the planned colony expansion is shown in Table 1.

The amount of water needed for extended human survival is around 0.6 kg/hr/person which includes water for consumption, hygiene, and everyday living in space (Bobe et al., 2007; Horneck et al., 2003, 2006). This estimate is based on space station living and, assuming water consumption is less in a micro-gravity environment, would increase up to 0.7 kg/hr/person to account for living with gravity. The amount required if demands from a growing colony (regolith processing, manufacturing, perchlorate remediation, plant growth, habitat maintenance, etc.) are added to human needs is estimated at 1.2 kg/hr/person. Assuming a water reclamation rate of at least 90% (similar to that of the space stations Salut, Mir, and the International Space Station, Bobe et al., 2007; Wieland, 1998), the amount needed from ISRU is 0.12 kg/hr/person. Some sources predict water reclamation rates as high as 96% (Horneck et al., 2006), but current technology reliably allows for 90%.

Table 1
Planned colony expansion, including crew size and colony population at any given year in the first 16 years of the colony.

Year	Mission #	New crew	Colony population
0	1	6	6
2	2	6	12
4	3	6	18
6	4	12	30
8	5	12	42
10	6	12	54
12	7	24	78
14	8	24	102
16	9	24	126

These numbers also take into account the requirements for hydrogen since hydrogen will most likely come from water electrolysis. This is because most of the accessible hydrogen on Mars is found in the form of H_2O (Krasnopolsky and Feldman, 2001; Boynton et al., 2002).

* Corresponding author.
E-mail addresses: miralphs@gmail.com (M. Ralphs), bfranz@usc.edu (B. Franz), tedb314@gmail.com (T. Baker), steve@howeindustries.net (S. Howe).

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Some water can be extracted from the martian atmosphere, but, in order to get enough to sustain a colony, extraction from the martian regolith will be the primary source of water. Several methods of water extraction from the regolith are considered viable and the extraction method will depend heavily on the site selected for the colony.

2. Colony water requirements

Water is needed for many applications for an extended colony on Mars beyond the 0.6 kg/hr/person to keep the humans alive and healthy. These applications fall into 5 categories: regolith processing, manufacturing, perchlorate remediation, plant growth, and habitat maintenance.

2.1. Regolith processing

Many useful compounds exist in the martian regolith in significant quantities including silica, alumina, iron oxide, magnesia, calcium oxide, and sulfates (Meyer, 1989; Stoker et al., 1993). The metallic oxides can be extracted by dissolution in sulfuric acid. To separate them, the solution is slowly neutralized using magnesia to selectively precipitate relatively pure oxide powders. These powders can be further processed to produce metallic ores (Berggren et al., 2009). This processing can require a significant volume of water on the order of hundreds of liters, but nearly all is reclaimed during processing. The makeup volume of water is therefore considered negligible.

2.2. Manufacturing

The regolith processing results in a number of useful materials including metallic iron powder, alumina, magnesia, silica, and residual regolith. These can be used to manufacture spare parts, structural members (Landis, 2009; Kirn et al., 2002), advanced ceramics, explosives (Dick et al., 1985), and cementitious products. Cementitious products are extremely useful for creating radiation shielding (Kirn et al., 2002), pathways, structures, and protective barriers, but they require a substantial amount of water. Concrete production requires approximately 0.4 $kg_{H_2O}/kg_{concrete}$ (Berggren et al., 2009). Concrete production will most likely use the most water out of all the manufactured materials because that water isn't easily reclaimed. And, although there may be more need for manufactured products towards the early stages of the colony, the amount required will be normalized to the amount of people in the colony. The estimated water required for manufacturing processes is 0.04 kg/hr/person.

2.3. Perchlorate remediation

Several perchlorate compounds are found on Mars that can be detrimental to human health. The perchlorate molecules are similar to iodine and block its receptors in the human body, causing hormone deficiencies (Wolff, 1998; Mukhi and Patiño, 2007; Davila et al., 2013). Therefore, it is imperative that the perchlorates are removed from all the materials that will be used by humans. This process is estimated to require 0.1 kg/hr/person of water, however, almost all of this water can be recycled and reused so the amount that ISRU will need to make up is considered negligible.

2.4. Plant growth

Plants are the most likely long term solution for food in a colony on Mars (Schulze-Makuch and Davies, 2010). And whether they are grown in hydroponic or potted systems, the plants will consume a certain amount of water. It is estimated that plants will require approximately 0.003 kg/hr/person of water that cannot be easily reclaimed by the environmental control and life support systems (ECLSS). This must, therefore, be produced by ISRU.

2.5. Habitat maintenance

Water needed for habitat maintenance will vary depending on the design of the habitat. A few uses of water that fall under this category are increasing grounding pin efficiency, resupply of fuel cells (Baird et al., 2003), and resupply of coolant in power systems. The estimated requirement for habitat maintenance is approximately 0.01 kg/hr/person of water.

3. Water extraction from the atmosphere

The martian atmosphere is made up of 0.03% H_2O (Muscatello and Santiago-Maldonado, 2012). Using an atmospheric processing system, similar to the Mars Atmospheric Resource Recovery System (MARRS) (England, 2001), it is plausible to extract 0.02 kg/hr/person of water from the atmosphere. This amount relates to the water that would be extracted from the atmosphere during the process of extracting the required oxygen for breathable air (Wieland, 1998). This also neglects oxygen regeneration in the habitat which would decrease the amount of water produced with this system. This system will grow as needed to support the oxygen needs of the growing colony. However, since this system will vary depending on the amount of oxygen regeneration in the habitat and 0.02 kg/hr/person is the maximum that would be produced, the actual amount of water that would be produced is small and nonconstant. Thus the atmosphere is not a good source for water to sustain an expanding colony.

4. Water extraction from regolith

The water available for extraction from the martian regolith is site dependent. At higher and lower latitudes, the majority of the water is found in icy soils and permafrost. Around the equator, most of the water content is found in hydrated minerals. There is some speculation that more water exists deeper in the regolith that may be available if a method is developed to drill down to it (Clifford, 1993), but at present this solution is not proven. But even near the equator where the water content is low, the regolith is very hard and difficult to remove in large quantities. It is estimated that a 2 ton excavator would be required to scoop up regolith containing more than 5% water content in a 4.5 cm wide scoop (Zacny et al., 2012a). However, advanced scooping systems are being developed for martian and lunar surfaces that are capable of excavating a significant amount of regolith (Mueller et al., 2013). The following excavation methods were chosen with the hard martian regolith in mind and are considered some of the most probable options for water extraction from the regolith.

4.1. Hydrated minerals

In the equatorial regions of Mars, the regolith is predicted to contain between 2% and 13% water content, most likely in the form of hydrated minerals (Muscatello and Santiago-Maldonado, 2012; McKay et al., 1993; Feldman et al., 2004). More energy is required to release the water from hydrated minerals than to sublimate the water from icy soils and permafrost. Although a few of the hydrated minerals found in the martian regolith have dehydration temperatures that are relatively low, as shown in Table 2, temperatures in excess of 600 °C are typically required to remove all the water from the hydrated minerals (Sanders and Mueller, 2015). However, the Sample Analysis on Mars (SAM) instrument on the Curiosity rover showed that a heating above 450 °C causes the