FOG ON MARS: POTENTIAL IMPLICATIONS FOR WATER EXTRACTION FROM THE MARTIAN ATMOSPHERE. Sergio A. Esteban[1] and Pascal Lee[2,3,4], [1]California State Polytechnic University Pomona, saesteban@cpp.edu, [2]SETI Institute, [3]Mars Institute, [4]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, USA.

Introduction: The future human exploration of Mars will be sustainable only if water is extracted in situ. Preliminary studies have shown that, in most locations at the surface of Mars, there is insufficient water in the atmosphere to make its extraction worthwhile. However, in some areas, the Martian atmosphere may locally far exceed water saturation commonly, allowing in-situ water extraction from the Martian atmosphere to become potentially viable. Areas that are commonly fog-filled, such as the floor of Valles Marineris, are among potential candidates.

Water Is Key. In October 2015, NASA convened "The First Landing Site/Exploration Zone Workshop" (LS/EZ). An important result of the meeting was a broadened realization that, in addition to allowing rich science, the ready availability of key resources for ISRU (In-Situ Resource Utliization) will be a driving criterion in the selection of a sustainable Mars LS/EZ.

Among key resources, water is by far the most important. Several modes of occurrence of water are known on Mars. Among them, water in the atmosphere. If water could be extracted practically and cost-effectively from the Martian atmosphere, the need to process large amounts of gritty surface materials would be alleviated. By avoiding large-scale regolith processing, extracting water from the atmosphere would also limit the forward contamination of Mars.

Water Extraction from the Martian Atmosphere. Early studies on the extraction of water from the Martian atmosphere have focused on processes that are conceptually promising for Mars but have limited operational heritage [e.g, 1, 2 and refs therein]. A more recent review at NASA SSERVI concluded that, considering the low water abundance in the (average) Martian atmosphere, extracting this water might not be cost-effective. At the average surface pressure on Mars of 6 mbar, the martian atmospheric density is ~0.020 kg/m3 and its water abundance is ~221 ppm. Thus, there is 1 kg of water in 250,000 m3 of atmosphere. In order to extract 5 metric tons of water per (Earth) year (i.e. 0.0095 kg (water)/min), one would have to process ~2400 m3 (atmosphere)/min, i.e. 84,000 CFM (cubic-feet per minute), assuming 100% efficiency. Given that an additional compression factor of 100 would have to be applied to achieve the standard inlet pressure of a compressor, the review concludes that a compressor capable of ~ 8.4 million CFM would be needed, ~ 14 larger than the largest industrial compressors available on Earth.

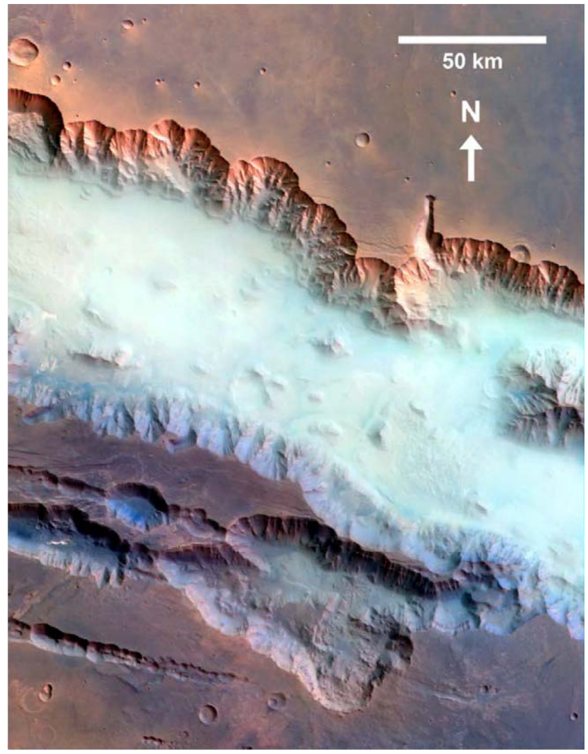

Figure 1. Morning fog in Valles Marineris, Mars (ESA/Mars Express/HRSC).

Fog On Mars: Fog is a near-surface manifestation of water in the atmosphere indicating it has exceeded water saturation and that condensation nuclei are present in suspension. Fog occurs on Mars in the form of ice fog, which is composed of water ice crystals [3]. Fog occurrences on Mars are most frequent during morning hours at low elevations in the Valles Marineris canyon system (Fig. 1).

Consideration of local environmental conditions on the floor of Valles Marineris lead to reduced requirement estimates for water extraction from the atmosphere. For a higher surface pressure of 10 mbar and associated atmospheric density of ~0.033 kg/m3, one would only have to process ~1300 m3 (atmosphere)/min, i.e., 46,000 CFM, to extract 5MT (water)/year. And if allowance for a potential water supersaturation factor of ~5 is made, as might occur in ice fog, the water abundance may reach 1000 ppm and the processing requirement drops to ~290 m3 (atm)/min, i.e. 10,000 CFM. Including the additional compression factor of 100, a compressor capable of 1 million CFM would suffice, i.e., only 1.7 times current max.

Atmospheric Water Extraction On Earth

There are currently a variety of atmospheric water extraction techniques and technologies that are operational on Earth. We review these processes and examine their potential application to extracting water from the Martian atmosphere. Some systems are simple while other systems prove to be on a higher level of sophistication. A system that extracts water from Mars' atmosphere can potentially be derived from one or more of these systems.

Fog Mesh Systems. One of the most common and economical methods of extracting water from fog is a fog mesh (of "fog net") system. These systems consist of a simple mesh and a collection system. The principle is to condense fog droplets onto a mesh and allow the condensed droplets to run down into a gutter [4]. Figure 2 is an example of a mesh system. These types of systems may vary in the surface area of the mesh, mesh material, coating, and mesh pattern. On Earth, a well-designed mesh can yield up to 12 L per day per square meter of the mesh in mild fog.

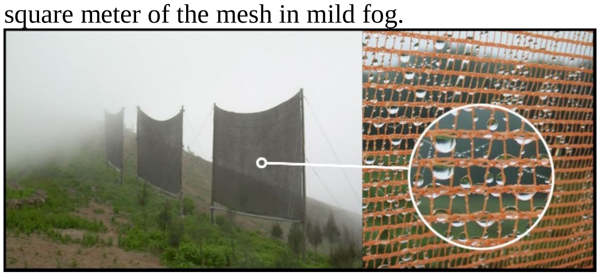

Figure 2. Fog mesh systems are exposed to the atmosphere. Water is extracted from the condensation of fog droplets onto these meshes.

Atmospheric Water Generators (AWG). An atmospheric water generators (AWG) is a commonly used device that extracts water from the atmosphere. AWG come in several types, varying in shape, size, efficiency, and water yield. Water-Gen's Large Scale Water Generator produces 6,000 L per day with a power requirement of 45 kW (at 26.7 °C and 60% RH).

The EcoloBlue 30E AWG produces 8-30 L of water per day with a power requirement of 750-1050 W (depending on humidity). Figure 3 shows two different AWGs. There are a few methods that AWGs utilize to extract water from the air. Some AWGs use condensation processes while others use hygroscopic processes.

Higher temperatures and pressures are capable of holding more water in the atmosphere. Fog forms when the atmosphere is unable to hold any more water (dew point). AWG condensation processes are used to lower ambient air down to its dew point. At the dew point water begins to condense. The condensed water is captured and then taken through a series of filters to remove harmful particles or microorganisms that are suspended in the water. There are some systems that introduce minerals into the water that are essential to the human body.

A desiccant, whether it is solid or "wet," is a substance that is used to absorb/adsorb water from air. Hygroscopic processes are employed in AWGs to extract water from the atmosphere. Solid desiccants such as zeolite or "wet" desiccants such as lithium chloride (brine solution) are used to adsorb water from a stream of air flow [5]. There is a second process that then extracts water from the desiccant. After this process is executed, the extracted water is taken through a filtration system that is similar to the one that was previously described.

Other Systems. In addition to the mentioned systems. There are other systems that collect water using different processes. MIT researchers have developed a solar powered device that uses metal organic frameworks to extract water from ambient air. Air wells are structures that are built in a specific way so that they can provoke the condensation of water. Many sites around the world also collect rain water. There are numerous other processes that are used on Earth to extract water from the air.

Atmospheric Water Extraction on Mars: Modifications to terrestrial systems could possibly enable the extraction of water from ice fog. Fog mesh systems extract water from liquid droplets, therefore a mesh system will fail with water ice crystals. AWGs on Earth are more flexible in their extraction processes. An AWG can be altered to extract water from ice crystals. Combined with a compressor similar (to within a factor of 2) to the largest industrial compressor systems in operational use on Earth, an AWG-based system could conceivably be designed for Mars.

Conclusion: Water is arguably the most important in-situ resource needed to sustain humans as they explore Mars. There are locations on Mars where atmospheric water abundances may be significantly higher than average, e.g., at low elevations in fog zones. A viable atmospheric water extracting process and system for Mars cannot be ruled out.

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