ATMOSPHERIC WATER VAPOR ADSORPTION FOR MARS IN SITU RESOURCE UTILIZATION. J. D. Williams, T. E. Bratkovich and T. R. A. Bussing, Adroit Systems, Inc., 411 108th Ave. NE, Ste 1080, Bellevue, WA 98004, (425) 450-3930

Introduction: ASI has successfully completed a Phase I SBIR contract to develop a method for extracting water vapor from the atmosphere of Mars in an efficient, lightweight, and reliable manner. Through the use of molecular sieve technology, the Water Vapor Adsorption Reactor (WAVAR) would provide a dependable source of water to future exploration missions from sources indigenous to the red planet. This water can be used as feedstock for propellant production, for direct human consumption, or as the basis for a multitude of industrial, agricultural and biological processes. Using locally available materials at the site of an interplanetary mission is known as in situ resource utilization (ISRU). Missions employing ISRU techniques can attain dramatic cost savings, while improving mission robustness, by reducing the amount of raw materials transported from Earth. The most important of these materials is water. WAVAR would meet this need, providing a crucial technology for future missions.

Water on Mars: The availability of water on Mars is undisputed. As illustrated in Figure 1, it is present in the polar caps, the regolith, the permafrost (speculative), and the atmosphere. Extraction of water from the regolith is technically feasible provided sufficient availability is demonstrated. Utilization of water from the polar caps would involve minimal processing and mining, but would entail landing on the polar ice sheet, which precludes effective solar power generation. Additionally, the polar regions are less likely to harbor signs of past or present life.

However, it is the Martian atmosphere that is currently the most highly characterized and globally distributed water source on the planet. Carbon dioxide makes up the bulk of the atmosphere on Mars, while water vapor makes up only a small fraction [1]. However, though the absolute humidity is low, the atmosphere is, for most times and locations, completely saturated (100% relative humidity) with respect to the nightly temperature minimum [2].

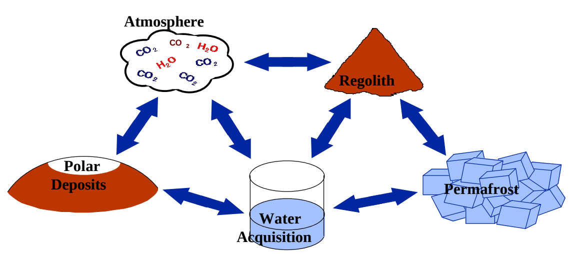

Figure 1. Martian water reservoirs.

The total water content of the Martian atmosphere is between 1 and 2 cubic kilometers [3]. However, concentration is strongly dependent on the season, latitude, and local topography. This was clearly demonstrated by column abundance data gathered from the Viking orbiters' Mars Atmospheric Water Detectors (MAWD), as shown in Figure 2. Unfortunately, column abundance data does not translate directly into available concentrations at ground level. For ground level concentrations, atmospheric scientists typically rely on two sources of data. The first is direct measurements of temperature (from which water vapor concentration can be inferred), like those taken by the Viking landers and Mars Pathfinder. The second source of data is generated by sophisticated computer simulations such as those run at NASA Ames Research Center by the Mars Atmosphere Global Circulation Modeling Group.

To operate WAVAR in as efficient a manner as possible, landing sites with water concentrations at or above the global average are desirable. If such landing sites are chosen, then WAVAR has the potential to become a critical technology for advanced robotic exploration, and an enabling technology for a sustained human presence on the red planet. Humid sites have the added advantage that they are attractive to exobiologists. In searching for signs of past or present life, the warmest, wettest spot on the planet is a likely candidate for initial exploration.

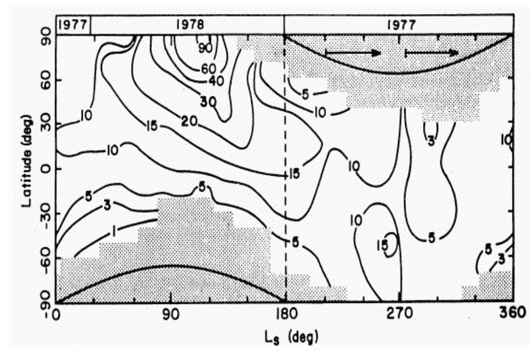

Figure 2: Column abundance of water vapor from Viking MAWD.

Adsorption: The water vapor adsorption reactor is a separation device. Water vapor must be extracted from the other constituents of the Martian atmosphere before it can be utilized. A particularly effective way for separating trace amounts water vapor from other gases is temperature-swing adsorption. This process involves two distinct steps operating in batch mode: 1) Adsorption, in which the water is separated from the other constituents at the surface of the adsorbent, and 2) Desorption, in which heat is used to drive the water off of the sorbent, after which it is collected. Temperature-swing adsorption is used in many applications, including large-scale dehumidification, and is a well-understood industrial process.

Adsorption techniques have been used in the chemical and petroleum industries for over 100 years, because it is a low-energy solution to the problem of separating mixed fluid species. Adsorption utilizes molecular sieves (the adsorbent) to selectively attract molecules of a fluid (the adsorbate) as it passes through a fixed bed. The molecular sieves are synthetically formulated crystalline structures of metal alumino-silicates (typically zeolites) that have been activated by removing the water of hydration. The result is a crystalline cage containing uniform micropores.

Free gaseous or liquid molecules are attracted to the surface of the adsorbent by Van der Waals forces [5]. These molecules are adsorbed selectively as a result of two microscopic phenomena: 1) molecular size-exclusivity of the adsorbent's micropore structure, and 2) the difference in sorption rates between the flow constituents. Adsorption itself is an exothermic process requiring no energy input other than that required to move the fluid. Removing the water from the bed (desorption), however, does require energy.

By tailoring the ion content (in this case, by introducing potassium ions) of an adsorbent, larger gas species can be excluded from capture. For water vapor adsorption on Mars, a logical choice of adsorbent is limited to those with an aperture of 3 Å (slightly larger than a water molecule), such as UOP (formerly Union Carbide) Molecular Sieve 3A. This adsorbent is highly specific to water, and will exclude other Martian atmospheric constituents such as CO_2, N_2, Ar, O_2 and CO. The pelletized form allows it to be packed easily into a bed to provide a large surface area while imposing an acceptable pressure drop; fine powders, gels, and pure thin-film crystals are also available.

Research Program: The primary goal of the Phase I program was to show WAVAR proof-of-concept through test and analysis. Four technical tasks were completed. The first of these tasks was the design and construction of a low-cost test rig, shown in Figure 3, to simulate the Martian atmosphere. The simulation included fidelity of pressure, temperature, humidity and gas composition. The test rig consisted of a vacuum, thermal control and data acquisition systems. The second task was to use this apparatus to conduct the first known proof-of-concept of water vapor adsorption by zeolite 3A in a Martian atmospheric environment. Further tests were run to collect adsorption data and to validate analytical models for the performance of zeolite 3A under these conditions.

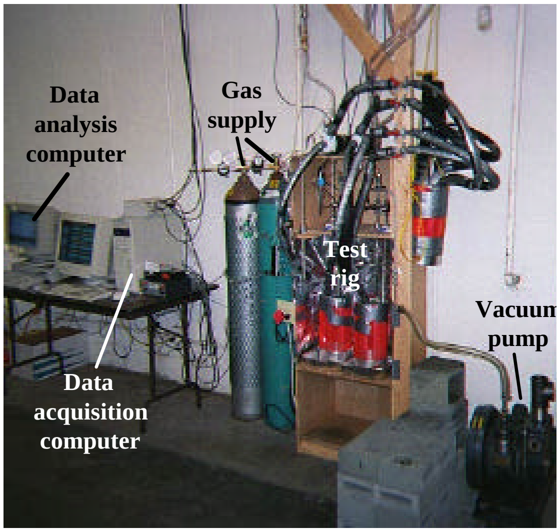

Figure 3: Water vapor adsorption experimental apparatus.

Task 3 of the Phase I program involved the formulation of a new, low-specific power WAVAR design which employs ambient wind patterns to eliminate blowers or fans. Atmospheric data was generated using the time and location accurate computational tools of the Mars Atmosphere Global Circulation Modeling Group. These data were supplied to a performance model, which was then integrated with mission analysis tools at Lockheed Martin Astronautics. An analysis was conducted of WAVAR-based Mars sample return mission. This showed significant benefits over conventional, imported hydrogen- and imported methane-based propellant production scenarios. The fourth task included a detailed test/analysis plan for future work.

The results of the Phase I effort clearly demonstrate the potential of WAVAR technology to dramatically reduce the costs of Mars sample return, robotic, and human exploration missions in the coming decades. With the attainment of proof-of-concept, and therefore Technology Readiness Level 3, WAVAR has been shown to be technologically feasible.

References: [1] Owen, T. et al. (1977), "The composition of the atmosphere at the surface of Mars," *J. Geophys. Res.*, Vol. 82, pp. 4635-4639. [2] Davies, D.W. (1979), "The relative humidity of Mars' atmosphere," *J. Geophys. Res.*, Vol. 84, pp. 8335-8340. [3] Carr, M.H., (1996) *Water on Mars*, Oxford University Press, pp. 3-46. [4] Jakosky, B.M., and Haberle, R.M. (1992), "The seasonal behavior of water on Mars," in *Mars*, Kieffer, H.H., et al., eds., The University of Arizona Press, Tucson, pp. 969-1016. [5] Foust, A.S. (1980), *Principles of unit operations*, John Wiley & Sons, Inc., New York, NY, pp. 384-419. [6] Ruthven, D.M., Shamshuzzaman, F., and Knaebel, K.S. (1994), *Pressure Swing Adsorption*, VCM Publishers, Inc., New York, NY, pp. 1-65.