FEASIBILITY STUDIES OF THE EXTRACTION OF WATER VAPOR FROM THE MARTIAN ATMOSPHERE BY ADSORPTION IN ZEOLITE 3A. A.P. Bruckner, S.C. Coons, and J.D. Williams, Aerospace and Energetics Research Program, University of Washington, Box 352250, Seattle, WA 98195-2250; bruckner@aa.washington.edu.

To achieve the maximum benefit from Martian in situ resource utilization (ISRU), an indigenous source of water must be developed. The possibility of obtaining water on Mars would make feasible the operation of a Sabatier/electrolysis (S/E) propellant plant without having to import the necessary seed hydrogen from Earth. This paper presents the results of a continuing feasibility study of the extraction of water vapor by adsorption from the Martian atmosphere.

Water on Mars is scarce. It is present as ice in the polar caps and perhaps as subsurface ice, and it is adsorbed in the regolith, but the atmosphere is the most highly characterized and globally distributed water source on the planet (0.03% by volume).[1] The desire to utilize this atmospheric water led to the development of the Water Vapor Adsorption Reactor (WAVAR) concept.[2,3,4] Past designs for extracting atmospheric water have invoked compression-cooling processes, which require high specific power inputs.[5] Water vapor separation by adsorption has fewer moving parts, and is both less massive and less energy intensive.[2]

WAVAR is conceptually very simple, as can be seen from Fig. 1. Martian atmosphere is brought into the system through a filter by an axial-flow fan. The filtered atmosphere is passed over the adsorbent bed, where the water vapor is removed from the flow by the zeolite molecular sieve. The disk-shaped bed is divided into sectors by insulating separators. Once a sector has reached saturation, it is rotated into a chamber and sealed off from the outside. A microwave emitter is engaged, heating the adsorbent bed sector and driving off the water vapor. The desorbed water vapor is condensed and piped to storage, where it is available for utilization by a S/E propellant production plant or for use by a manned Mars base. The WAVAR design has only six components: a filter, a fan, an adsorption bed, a regeneration unit, a condenser, and a control system. Figure 2 shows a vertical configuration and the dimensions used for the simulations presented here.

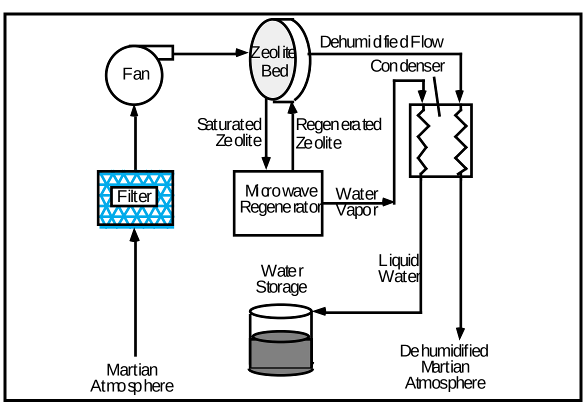

Fig. 1 Schematic of WAVAR, the Water Vapor Adsorption Reactor.

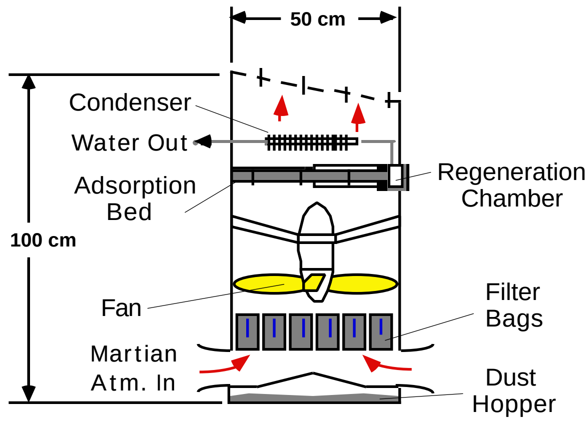

Fig. 2 Vertical WAVAR configuration used for simulation.

For water vapor adsorption on Mars the 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 is effective at excluding CO_2. The adsorption and desorption characteristics of zeolite 3A were computed using the Dubanin-Polanyi model.[3] For desorption at 6 torr, starting at an ambient temperature of 220 K, the optimum desorption temperature is 420 K and the corresponding specific energy of desorption is 5.48 MJ/kg of water recovered.

Preliminary microwave desorption experiments were performed with saturated 50 g samples of zeolite 3A. Adsorption was done passively, with final loading determined by weight. The samples were then heated and weighed at 10 sec intervals and typical desorption curves were obtained.[3]

The largest power draw in the WAVAR system is that of the fan, and determining its power requires examination of all the pressure drops throughout the system. The two main sources of pressure drop, ΔP, are the filter and the adsorption bed, the latter being dominant. All sources of ΔP are functions of the flow velocity. The pressure drop of the zeolite bed was computed using a linear approximation to the Chilton-Colburn and Colburn-J Factor correlations over the range of Reynolds numbers of interest (5-120).[3] The fan was modeled as a four-bladed propeller with an efficiency of 85%, and its power requirement was found using classical momentum theory.[6]

For a given available power the amount of water collected by WAVAR was computed iteratively, using the expressions for fan power and desorption

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power, both being dependent on the mass flow rate generated by the fan.

To make a credible determination of the performance of the WAVAR, actual Martian atmospheric water data from the Viking 1 (VL-1) mission were used in the simulation. Local humidity data were obtained from Ryan *et al.*,[7] who deduced atmospheric water content from frost point temperature data. The assumed design parameters used for the simulation with the VL-1 data set were as follows: bed dia. 50 cm, bed depth 4 cm, void fraction 0.33, pellet dia. 3.25 mm, and motor, fan, microwave, and extraction efficiencies of 0.9, 0.85, 0.7 and 0.9, respectively.

Figure 3 displays the variation in water extracted each sol across a 250 sol run for total power levels of 100, 200, and 400 W. Table 2 shows the totals for the entire run. The amount of water produced is not a linear function of the available power, because higher throughput requires higher mass flow and fan speed, and thus higher flow velocity through the bed, which increases the pressure drop losses. The daily rates of water production and the 250 sol totals turned out to be quite low, and the specific energy relatively high compared to our previous results[2] (but still considerably better than for the compression-cooling concept[5]), reflecting the low average humidity of the VL-1 site, lower than the global average of 0.03%.

In our earlier work[2] we had assumed the more optimistic conditions used by Meyer and McKay (0.06% humidity) for their compression-cooling concept.[5] Although such favorable conditions were not observed by either of the Viking landers 20 years ago, this does not preclude their existence. Water is a highly variable component of the Martian atmosphere and is strongly dependent on the season, latitude, and local topography.[1] For example, at high latitudes in the northern hemisphere during summer the humidity is significantly higher than the global average. Also, the recent Pathfinder mission to Mars has returned temperature data warmer than those at the two Viking sites and close to the assumptions made by Meyer and McKay, potentially indicating higher humidity. For every 5 K drop in the frost point temperature the available water is cut roughly in half and quickly becomes minuscule if the frost point drops below about 190 K, as is the case after sol 250 at VL-1.

These considerations highlight the importance of landing site selection for a mission using a WAVAR. If attractive landing sites with frost points in the 200-210 K range are found, then WAVAR has the potential to become an enabling technology for advanced unmanned exploration, as well as to provide supplemental water for the first human colonization of the red planet. Using Mars' atmosphere as a source of water for ISRU remains an attractive option, due to the global distribution of atmospheric water, and because water will be a critical resource for the exploration and colonization of Mars.

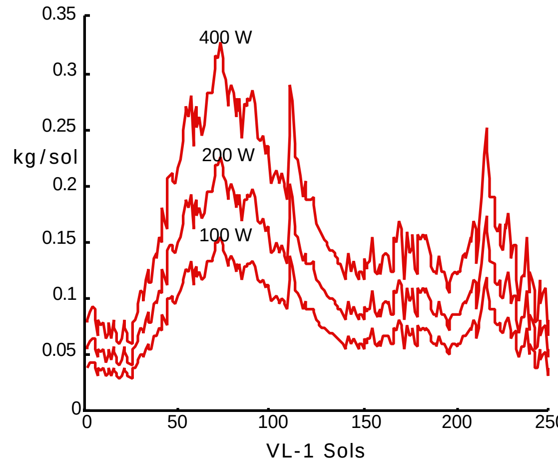

Fig. 3 Water extraction rate, sols 1-250 at VL-1 site.

Table 2 Sol 1-250 simulation results.

	100 W	**200 W**	**400 W**
Tot. Energy (kW-hr)	615	1230	2460
Water Extracted (kg)	20	29	41
Specific Energy (kW-hrs/kg)	31	43	60
Avg. Flow Vel. (m/s)	6.1	8.8	12.6
Avg. Motor Speed (RPM)	485	703	1010

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