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THE "MARTIAN FARMER"
MINING WATER FROM THE MARTIAN REGOLITH

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ABSTRACT

Mars' atmosphere is saturated with water. On Mars, saturated means a partial pressure of about 0.1 Pa (compared with about 600 Pa on Earth (Moran & Shapiro, 2000)). That represents only 1 mg of water in every cubic meter of Martian air. In contrast, every kilogram of Martian regolith (soil) contains up to 40 grams of water (Zent & Quinn, 1997). A sabatier reactor big enough to fuel an Earth Return Vehicle such as that used in Mars Direct requires 9.7 grams of hydrogen per hour (Zubrin *et al*., 1997), which can be produced from 88.1 g of water, or as much water as is contained in a little over 2 kg of soil. This paper discusses several methods for extracting water from atmosphere enhanced with water from the regolith. Methods include the WAVAR system previously discussed by Grover & Bruckner in the 1998 Mars Society Conference; freezing water out with a thermoelectric conveyor belt; and using a compression/refrigeration unit to first compress the bulk atmosphere and then freeze out the water. In all cases it is seen that the Martian Farmer is an enabling technology.

THE MARTIAN FARMER

The Martian Farmer is an autonomous rover designed to collect water from the Martian regolith and store it for human consumption, life support, *in situ* propellant production, or any number of other uses. The platform of the Martian Farmer is a rover roughly 3 meters long by 1 meter wide and less than 1 meter deep. Such a rover would be covered with solar panels supplying it with 150 watts of power. On each corner of the rover, a simple greenhouse dome would be deployed. Each dome would have a radius of 1 meter and cover an area of 3.1 square meters. The bottom of each dome would be a flexible skirt (think of saran wrap cut in vertical strips) that could traverse easily over small rocks.

The sun heats the air and regolith under each dome, releasing water from the regolith into the atmosphere. Between the domes and under the solar panels would be a system for extracting water from the moist Martian air. Air is drawn from under the four domes and through the extraction system. The water is removed and stored on board. Periodically the on board water stores are pumped or taken to a central storage facility.

According to my calculations (available upon request from salinay@umich.edu, but beyond the scope of this paper), the area covered by each dome has 50 g of water available for

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release. The solar energy available, however, is enough to release 49 g of water from under each dome every hour (see calculations in the WAVAR section). Please note that warm, wet air leaking out from under the dome will frost out around the dome edges as it comes in contact with the colder outside air. For this reason, it may be advantageous to have the rear domes slightly (1-2 cm) larger than the forward domes so that they can sublimate this frost ring.

WATER VAPOR ADSORPTION REACTOR (WAVAR)

One of the most promising techniques for atmospheric water extraction, the WAVAR reactor adsorbs water from the Martian atmosphere into a bed of Zeolite 3A (a sort of sponge) from which it is desorbed (released) and piped into a storage device. This concept has been developed under Adam P. Bruckner of the University of Washington [4,5,6]. His teams have run simulations with 100, 200, and 400 W reactors under various Mars conditions. For a more extensive general description of how WAVAR works, see the Proceedings of the Founding Convention of the Mars Society: Part II [4]. For a more detailed technical description, see the 33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit [6].

The energy requirements for the WAVAR device are determined by the amount of water available in the airflow. "The available water is cut roughly in half for every 5 K drop in the frost point temperature. Comparing how much water is available at the Viking Lander 1 site (based on average frost point) with the optimistic assumed value, there is 20 times more water available at 213 K than at 193 K. The available water quickly becomes minuscule if the frost point temperature begins dropping below 200 K, and correspondingly, the energy requirements for extraction become unacceptably high" [6]. WAVAR draws 8000 cubic meters of Martian air every hour [6]. This much atmosphere contains only 8 grams of water.

Under nominal Martian conditions, each dome can release 49 grams of water per hour. (Given the amount of water in the regolith, the Martian Farmer needs to move 4 meters per hour to release this amount of water.) This much water raises the frost point of the air reaching the WAVAR from 195 K to 220 K, raising the water content from 1 mg/m^3 to 25.5 mg/m^3. The greenhouse makes WAVAR a much more feasible water extraction technology. While studies show more of the available water can be extracted at higher wattage, only the 100 watt WAVAR fits in the Martian Farmer's 150 watt energy budget. By increasing the available water by an order of magnitude, however, even the low energy WAVAR could capture copious water for storage and later use. Operating for 8 hours per sol, the WAVAR can generate 1.6 kg of water, more than half the 2.2 kg/sol needed for a manned Mars mission [4].

As you can see, WAVAR is well suited to the Martian Farmer: water available to the WAVAR is increased by an order of magnitude; and the power requirements of the WAVAR are well within the Martian Farmer's energy budget.

THERMOELECTRIC CONVEYOR BELT

Originally discussed at the Think Mars conference at MIT in the fall of 1999,[1] I have not seen the concept of the thermoelectric conveyor belt discussed anywhere in the existing literature, so I shall attempt to give a complete description here. The main idea: keep a refrigerator door open so it collects water in the form of frost. A thermoelectric refrigerator consists of two dissimilar metals with a voltage applied across them causing one side to heat up while the other side cools down. It has no refrigerant to lose, and is therefore easier to deal with far from maintenance facilities. Pairs of these metal strips make up the slats of the conveyor belt. They are held closely together along a straight section where ice forms. One by one the slats peel off and turn a corner while the ice, held together by it's own crystalline structure (and perhaps released from the slat by a reversal of current and the consequent heating of the surface of the slat), moves off the conveyor into a collection area. When a large enough sheet of ice has come off the belt, it can be cut at a specified length and added to a stack of such ice sheets, stored for further processing at a later time.

The major constraint on the thermoelectric conveyor belt is that the water frozen onto the belt must be thick enough to generate usable sheets of ice during each sol. The speed of the conveyor belt can control how thick a sheet of ice could theoretically get, but there must also be enough water available to reach that theoretical capacity of the sheet. Thermoelectric couples with a temperature difference of over 80 K are available [8]. Splitting this difference keeps the cold side of the thermoelectric refrigerator 40 K below the ambient temperature, allowing us to potentially extract 99.7% of the water from any atmosphere coming in contact with the refrigeration unit [6]. If the conveyor belt is 1 meter long by 10 cm wide, then 1 gram of water evenly distributed on its surface will produce a film 10 micrometers thick. If we force as much air over the conveyor as we do through the WAVAR, from the ambient Martian air we can remove 8 grams of water per hour, producing a sheet 0.64 mm thick after an 8 hour sol. Not only is this sheet unacceptably thin, but I have serious doubts as to the ability of a thermoelectric refrigerator to remove the water from 8000 cubic meters every hour. That is a lot of air to process!

How do things change when we add the greenhouse domes? First of all, the air going over the conveyor belt will be heated, so there will be a larger temperature difference. This can only help the device. Secondly, up to 200 grams of water will be available each hour at half the flow rate of the WAVAR, and the airflow rate can be further reduced without significantly reducing the available water. 200 grams of water is enough for an ice sheet 2 mm thick to be produced every hour, or 1.6 kg of ice each sol if it is in operation 8 hours/sol. The speed of the belt can be adjusted to optimize ice sheet thickness, but typical values are 0.5-2.0 cm [8].[2]
As can be seen, the thermoelectric conveyor belt is a technology that is enabled by the Martian Farmer's greenhouse dome. Rough calculations show that the Martian Farmer can supply 1/3 the energy the refrigerator would need to extract this amount of water.

COMPRESSION & REFRIGERATION

[1] In the original discussion, the refrigerator on a Volvo was cited as an example of a thermoelectric refrigeration system, and the concept was therefore referred to as the "Volvo Device."

[2] The equation of thickness, including derivation, is available upon request (salinay@umich.edu).

W. Mitchell Clapp described a compression, refrigeration apparatus to remove water from the Martian atmosphere during The Case for Mars II [9]. The atmosphere is drawn into an axial compressor, and then forced through an annulus between a cylindrical refrigeration unit and the wall of the device. Given a frost point of 213 K, Mitchell finds that 100,000 cubic meters of atmosphere are required to generate 2.79 kg of water per sol, given that it operates only during 6 hours of maximum solar input. According to data from the first Viking lander, the frost point on Mars was not observed to rise above 205 K naturally during the first 350 sols of the lander's stay. I recalculated the numbers for a frost point of 195 K and found merely 100 grams of water could be generated from the same mass flow of atmosphere.

Even with the Martian Farmer's greenhouse domes, the frost point of so much air can only be raised to 205 from 195 K, or 210 from 205 K [6]. Using the 210 K frost point, 4.4 kg of water are available, of which the compression, refrigeration cycle recovers just under 20%. This yields 770 grams of water per sol, more than enough for a small sample return mission [10], but only one third as much as would be needed for a manned mission. Unfortunately the Martian Farmer cannot supply the enormous amounts of power this method requires.

This technology may be enabled by the Martian Farmer, but it does not show as much promise as the other two methods. By reducing the flow rate, and extracting a larger percentage of the available water, more water may be extractable. Some external source of power is required, however.

CONCLUSION

All three methods of extracting water from the Martian atmosphere benefit by additional water extracted from the regolith. The WAVAR moves from a borderline possibility an enabling technology. The thermoelectric conveyor belt, something that cannot function in ambient Martian conditions, can function if feed atmosphere from under a greenhouse dome. The compression and refrigeration device comes much closer to the design assumption if it draws enriched air from the domes. The Martian Farmer can supply not only moist air, but also power for the extraction devices. However, the WAVAR is the only device that can be entirely supplied by the rover's modest energy budget.

I feel further research into all enabling technologies is warranted, and I would be glad to share my calculations and efforts with anyone working on these technologies. Please contact me by email.

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