EVAPORATION RATES FOR LIQUID WATER AND ICE UNDER CURRENT MARTIAN CONDITIONS.

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Introduction: A number of studies have been concerned with the evaporation rates under martian conditions in order to place limits on the possible survival time of both liquid water and ice exposed on the surface of Mars [1-3]. Such studies also aid in assessing the efficacy of an overlying layer of dust or loose regolith material in providing a barrier to free evaporation and thus prolong the lifetime of water in locations where its availability to putative living organisms would be significant [4-5]. A better quantitative understanding of the effects of phase changes of water in the near surface environment would also aid the evaluation of the possible role of water in the formation of currently observed features, such as gullies in cliff walls and relatively short-term changes in the albedo of small surface areas ("dark stains") [6-8].

Laboratory measurements aimed at refinement of our knowledge of these values are described here. The establishment of accurate values for evaporation rates and their dependence on the physical conditions of temperature, pressure and energy input, is an important benchmark for the further investigation of the efficacy of barriers to free evaporation in providing a prolonged period of survival of the water, particularly as a liquid.

Experimental: Our measurements were performed in a 61 cm diameter, 208 cm tall stainless steel cylinderical vacuum chamber that can be cooled (with liquid nitrogen, methanol/dry ice, and chilled water) and heated (with heater wire, to about 100 °C) while containing an atmosphere similar to that of Mars. Eleven thermocouples monitor the temperature at various places on the chamber walls, in the chamber atmosphere, on the sample surface and in the coolant reservoir. Hygrometers record the partial pressure of water vapor 2.5 and 20 cm from the surface of the sample. The manufacturer's calibration of the hygrometers was checked against the pressure increase as water evaporated under closed system conditions.

Our experimental set-up consisted of a beaker containing distilled water and ice with a gauze holding the ice in the lower half of the beaker. The chamber was filled with CO_2, cooled down, the beaker placed on the balance, and the chamber pumped down to 5.25 Torr (7 mb). The temperatures of the walls of the chamber, the atmosphere in the chamber and the water were kept at ~0°C. After a few minutes to settle down, mass, temperatures, pressures and humidity were recorded every 10 minutes. After about sixty minutes, an ice

layer formed on the surface of the water and the present run was assumed to come to an end. Advective conditions were achieved by suspending a cloth bag containing dry ice in the chamber to condense the water vapor on its surface. The CO_2 evaporating from the
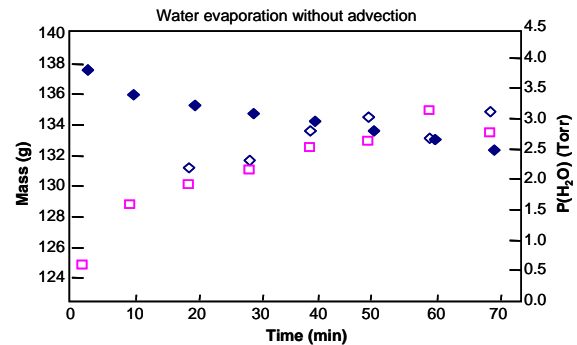

Fig. 1. Mass (filled symbols) and $P(H_2O)$ measurements (open symbols) at 10-minute intervals during the experiment. The $P(H_2O)$ measurements were made 2.5 cm (diamonds) and 20 cm (squares) from the surface.
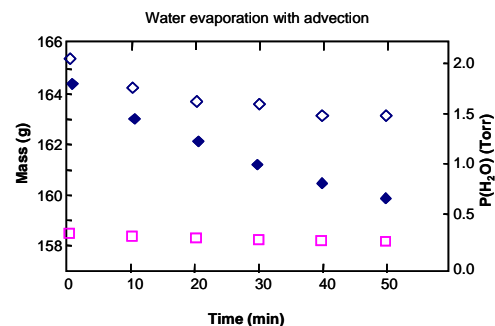

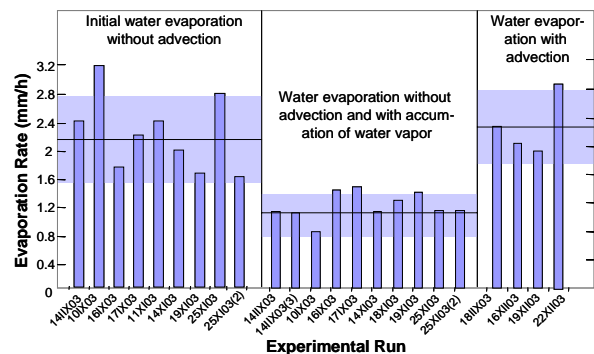Fig. 2. As Fig. 1 but under advective conditions.

Fig. 3. The initial evaporation rate without advection is similar to the evaporation rate for water under advective conditions, which is about twice the rate observed under non-convective conditions when the water vapor has accumulated for ~30 minutes.

dry ice was occasionally pumped away to maintain the desired pressure. This dynamic method of achieving advective conditions will soon be replaced with a static method of a liquid nitrogen cooled cold finger.

Results: Figure 1 shows data for a run without advection and in which water vapor is allowed to build up above the liquid. Initially the rate of evaporation is 2.8 mm/h but after a few minutes the rate decreases monotonously to ~1.2 mm/h after 30 min. During this process the vapor pressure of water increased from essentially zero to about 3 torr at both 2.5 and 20 cm from the samples. Figure 2 shows an example of data obtained under advective conditions. In this instance the evaporation rate settles down to ~1.8 mm/h in this example and water vapor pressures are lower than in Fig. 1, being essentially at the detection limit 20 cm above the sample.

To date, we have made 14 runs and these data are summarized in Fig. 3. Without advection the average initial evaporation rate is 2.2±0.6 mm/h (9 determinations, 1 σ uncertainty) while the evaporation rate after accumulation of water vapor for ~30 min is 1.2±2 (10 determinations, 1σ uncertainty). For the advective case, the average evaporation rate for 4 determinations is 2.2±0.4 mm/h (1σ uncertainty).

Discussion of data: The maximum evaporation rate corresponds to conditions where the ice or liquid evaporates freely into a dry CO_2 atmosphere. In the hypothetical case of a quiescent atmosphere, with no wind, the initial evaporation rate will not be attenuated by any barrier imposed by the accumulation of water vapor at the surface through which the vapor phase molecules must diffuse. Under conditions where the vapor is removed from the surface by advection, the evaporation rate will be the maximum possible for the particular conditions of ice or liquid temperature and the atmospheric temperature and pressure at the surface. Thus our initial evaporation rates under non-advective conditions are the same as our evaporation rates under advective conditions, 2.2 mm/h, with final evaporation rates under non-advective conditions being about a factor or two lower, 1.2 mm/h.

Prior theoretical estimates of water evaporation on Mars. Hecht [2] recently summarized theoretical treatments of Holman and Ingersoll and - extrapolating his figure 7 to 5.25 torr – the methods suggest values for Mars of 0.4 mm/h and 0.8 mm/h, respectively. Both methods assume advective conditions and compare with our value of 1.2 mm/h.

Our observation that the water vapor pressure under advective conditions is several torr at 2.5 cm from the surface and close to the detection limit of our hygrometers (~0.5 torr) at 20 cm is consistent with diffu-

sion limited escape of the water vapor where the water gradient can be described by Fick's law.

Thus both the evaporation rates we determine and the water vapor gradient we observe under advective conditions are consistent with existing theory.
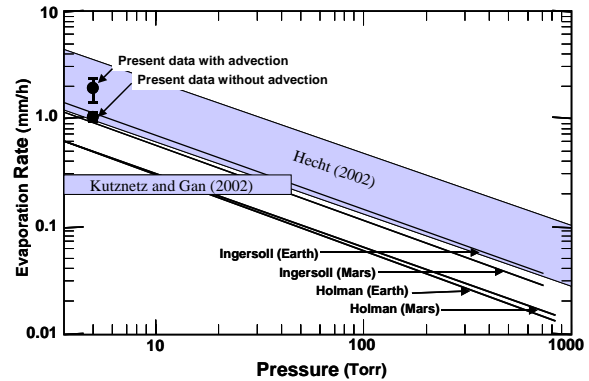

Fig. 4. Comparison of the present data with previous theoretical (Ingersoll and Holman) and experimental (Hecht and Kutznetz and Gan) data.

Prior experimental estimates of water evaporation on Mars. We are aware of two recent experimentally-based estimates of water evporation rates under martian conditions. Hecht published three sets of measurements at pressures that varied from 8 torr to atmospheric pressure and extrapolating his data to 5.21 torr yields an estimate of 2±1 mm/h [2]. Kutznetz and Gan reported three measurements between 5 and ~12 torr which average 0.22±0.02 mm/h [3]. Our determinations, while considerably more precise, are in agreement with experimental determinations of Hecht [2] .

Implications for Mars. We suggest that the upper limit for water evaporation on Mars is close to 1.1 mm/h. In any real case, factors that have been discussed in the literature - such as surface coatings of snow, ice or dust, or the lack of winds and a particularly quiescent atmosphere - would lower this value. This value therefore represents a realistic constraint on theoretical treatments of water evaporation in Mars.

References: [1] Ingersoll A. P. (1970) Science 168, 972. [2] Hecht M. H. (2002) *Icarus, 156,* 373. [3] Kuznetz L. H. and Gan D. C. (2002) *Astrobiology, 2,* 183. [4] Clow C. D. (1987) *Icarus, 72,* 95. [5] Farmer C. B. (1976) *Icarus, 289,* 279. [6] Malin M. C. and Edgett K. S. (2000) *Icarus, 288,* 2330. [7] Sullivan et al. (2001) *JGR.* 106, 23607. [8] Schorghofer N. et al. (2002) *GRL* 9, No. 23, 2126, doi:10,1029/2002GL015889