EFFECT OF WIND ON THE STABILITY OF WATER ICE UNDER MARTIAN CONDITIONS. J.D. Chittenden[1,2], D.W.G. Sears[1,2], V. Chevrier[1,2]. [1]W.M. Keck Laboratory for Space Simulations, Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701, [2]Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701; <jchitte@uark.edu>

Introduction: Past evidence of water on Mars has been well documented and discussed at length. However, the mechanism by which liquid water could be present on current day Mars is poorly understood. We have performed experimental studies in order to better understand how water behaves on Mars. Prior work focused on measuring the evaporation rates of pure water and comparison with model dependent theoretical calculations published by Ingersoll [1,2]. In addition, the dependence of the evaporation rates of brines as a function of temperature has been measured under Martian conditions [3].

Current work is focused on determining the dependence of the sublimation rate of water ice on wind velocity from a theoretical and experimental point of view. The presence of wind could play a significant role in the formation and stability of liquid water related to surface features such as gullies. [4]

Theory: There are two cases for evaporation and sublimation of water and water ice; free convection and forced convection. For free convection, the evaporation rate is governed by the removal of water vapor molecules away from the surface due to the natural buoyancy of the lighter water molecules moving through a heavier CO_2 atmosphere. In this situation, factors such as humidity, atmospheric pressure and composition, and temperature governed the rate at which the water evaporated as described by the Ingersoll equation [1]:

$$E = 0.64\Delta\eta\rho D\left[\frac{\left(\frac{\Delta\rho}{\rho}\right)g}{\upsilon^2}\right]^{\frac{1}{3}} \qquad (1)$$

where Δη is the concentration difference, ρ is the atmospheric density, D is the diffusion coefficient of water vapor through CO_2(g), Δρ/ρ is relative density difference between water and the atmosphere, g is the gravitation constant, and υ is the kinematic viscosity.

However, in forced convection, the water vapor is forcibly removed by atmospheric circulation and the evaporation rate is governed by the ratio of the inertial force of the wind to the viscous force of the atmosphere. In this circumstance, equation 1 becomes

$$E = 2.14\Delta\eta\rho D\left[\frac{v\rho}{\mu}\right]^{\frac{1}{2}} \qquad (2)$$

where μ is the dynamic viscosity, and v is the wind velocity. It is assumed that the water molecules are being removed by a continuous stream of atmosphere over the surface of water ice. When solved as a function of wind velocity, we obtain figure 1.

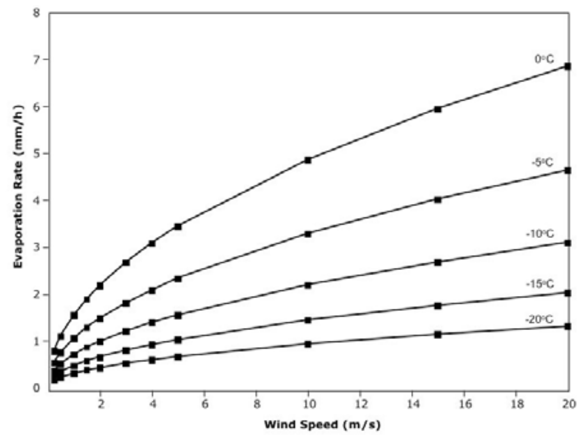

Figure 1. Sublimation rate of water ice as a function of wind velocity. Each theoretical line describes the evaporation rate at temperatures ranging from 0°C (top line) to -20°C (bottom line).

With addition of wind, the sublimation rate of water ice should increase by a factor of 9 as the wind velocity over the ice surface increases from 0.25 m/s to 20 m/s. It is also important to note that temperature has a significant effect on the sublimation rate of ice. Temperature effects were first described by Sears and Chittenden for concentrated brine solutions [3]. In the case of water ice under advective conditions, the sublimation rate of ice decreases by a factor of 5.29 at all wind velocities when the temperature decreases from 0°C to -20°C. Therefore, the sublimation rate of the water ice decreases significantly as temperature decreases even at high wind velocities.

The velocity at which free convection gives way to forced convection is given by

$$v = \sqrt{gL} \qquad (3)$$

where g is acceleration due to gravity and L is the scale length for the process, probably ~1 m. This yields a value of v = ~2 m/s.

The objective of the present experiments was to test these ideas by measuring the sublimation rate of water ice in the presence of a wind. To date we have experimented with wind velocities up to 2.5 m/s. We shortly intend to extent this work to higher velocities.

Experimental: Experiments were run in our environmental simulation chamber. The chamber was evacuated to < 0.09 mbar, filled dry $CO_{2(g)}$ to one atmosphere, and cooled to ~0°C using a methanol/dry-ice slurry. Pure water was frozen and placed on a top loading analytical balance in the chamber with thermocouple on the ice surface. A fan was located so as to push air across ice surface. The assembly was lowered into the chamber, the chamber was sealed, evacuated to 7 mbar, and mass, pressure, temperature, and humidity recorded automatically every 15 seconds. The fan speed was increased every 10 minutes until 2.19 m/s was reached. The pressure was maintained between 6.9 and 7.2 mbar. Two digital television cameras viewed the beaker and fan system.

Three experiments were performed. The first experiment allowed the ice to sublimate while allowing the p_{H2O} to increase in the chamber (Fig 2, filled squares). The second experiment allowed for the sublimation of the ice while exchanging the chamber atmosphere with fresh CO_2(g). The exchanging atmosphere kept the humidity inside the chamber at approximately 1%. (Fig 2, open circles). During the third experiment, the CO_2(g) was blown in front of the fan assembly to allow for dry CO_2 to flow across the ice surface. The temperature of the samples decreased during chamber evacuation to approximately –15°C due to evaporative cooling, but since this was reproducible between experiments no correction has been applied for the present purposes.

Results: Fig. 2 shows the summary of data collected compared with the theory line calculated from equation 2 for a sample at -15°C. As expected, since at these low wind velocities we did not enter the realm of forced convection, we found no correlation between wind velocity and sublimation rate. However, we observe an average variation from 0.21±0.02 mm/h to 0.45±0.02 mm/h from the humid to the dry and then to 0.60±0.03 mm/h when blowing pure CO_2 on the surface.

Discussion: As expected from our earlier discussion, wind speed does not effect the sublimation rate but instead evaporation rates are governed by the partial pressure of water at the ice surface ($\Delta\eta$ in equation 1). As seen in Fig. 2, the sublimation rate of ice increases as the p_{H2O} at the ice surface decreases, the first experiment (filled squares) with the highest p_{H2O} and the dry CO_2 experiment (filled circles) with the lowest p_{H2O} at the ice surface.

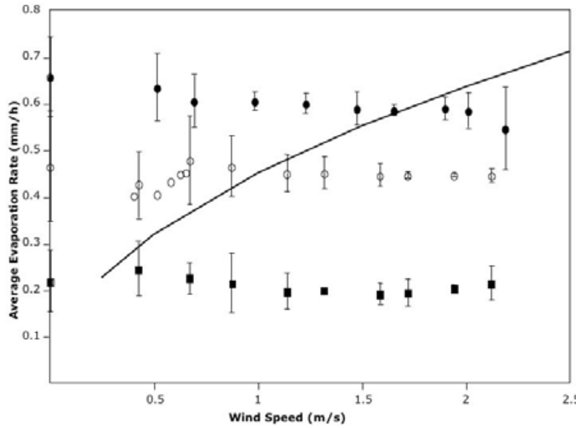

Figure 2. Data for three experimental set-ups to determine effect of wind speed. Filled squares represent experiments where p_{H2O} was allowed to increase while keeping p_{atm} constant. Open circles represent experiments where the atmosphere was exchanged with dry CO_2. Closed circles represent data where dry CO_2 was bled into the chamber in front of the fan assembly. The solid line represents the theoretical trend for water ice at -15°C.

Conclusions: The partial pressure of water at the ice surface plays a significant effect on the sublimation rate of ice. As predicted by theory, low wind velocities (0 - 2.2 m/s) used in the present experiment did not play a significant role in the sublimation of water ice since free convection prevailed in the chamber. Future experiments will be performed using higher wind velocities in order to quantify the effect of advective conditions on the stability of water ice.

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