

REGOLITH CONTROL OF ATMOSPHERIC WATER VAPOR ON MARS: ANALYSIS OF PHOENIX TECP DATA. H. N. Farris¹, M. B. Conner^{1,2}, E. G. Rivera-Valentin³, V. F. Chevrier¹, ¹Arkansas Center for Space and Planetary Sciences, University of Arkansas, Fayetteville, AR 72701 hnfarris@uark.edu, ²Department of Physics, Reed College, Portland, OR 97202, ³Arecibo Observatory, National Astronomy and Ionosphere Center, Arecibo, Puerto Rico.

Introduction: NASA Phoenix landed in the Northern arctic plane (Vastitas Borealis 68.2 N, 234.3 E) of Mars in May 2008; a region characterized by near-surface ice. The Thermal Electric Conductivity Probe (TECP) collected temperature, relative humidity, and electric conductivity measurements as the surface [1, 2]. Temperature versus relative humidity data from Phoenix was the first time a detailed investigation of the diurnal water cycle on Mars could be conducted. A proposed evaporation-adsorption cycle suggests that regolith parameters control relative humidity through the adsorption and desorption of atmospheric water vapor [3,4] (Fig. 1). Adsorption of liquid water onto a substrate can be expressed through two layer-driven theories: Langmuir, which accounts for a monolayer (one molecular thickness) of liquid and BET, which accounts for piling up of multilayers of liquid [5].

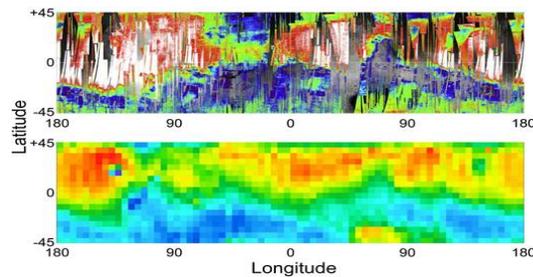


Figure 1. Comparison between **top:** the distribution of nanophase ferric oxides as seen by Mars Express OMEGA (high abundance: white, low: blue) [6] and **bottom:** the humidity in the atmosphere, ranging from 0 (blue) to ~30 (red), as observed by MGS-TES in the equatorial regions [7, 8]. The similarity of both maps suggests the ferric oxides abundant in the regolith could control the atmospheric humidity through adsorption and desorption [3].

Methodology: TECP data was downloaded from the Planetary Data System (PDS) for sols 0-150. Saturation vapor pressure, P_{sat} , was calculated using the board temperature, T , which will suffice as the atmospheric pressure. The pressure of water, $P_{\text{H}_2\text{O}}$, was calculated using the vapor pressure at the frost point temperature. Relative humidity could then be easily calculated using $P_{\text{H}_2\text{O}}/P_{\text{sat}}$. Relative humidity was then plotted against temperature in Origin 9.1. Reference values from the literature (Table 1) were used to model the data using Langmuir and BET adsorption theory, where relative humidity is:

$$RH = \frac{-C - 2\theta + C\theta \frac{\sqrt{C}\sqrt{C + 4\theta - 2C\theta + C\theta^2}}{\theta}}{2\theta(C - 1)}$$

Where C is the sticking coefficient and θ is a surface coverage and substituting C for:

$$C = C_0 \exp \left[\frac{-\Delta H}{R} \left(\frac{1}{T} - \frac{1}{T_0} \right) \right]$$

Where sticking coefficient is a function of temperature (T), enthalpy (ΔH), and ideal gas constant (R). Surface coverage is expressed by:

$$P_{\text{H}_2\text{O}} = \frac{\theta}{\alpha(1 - \theta)}$$

where α is a temperature dependent regolith parameter [9].

Material	θ	Θ (+/-)	C	ΔH (kJ/mol)	ΔH (+/-)	T (K)
JSC Mars 1 ³	0.04	0.004	103.4	49.952	1.372	243
Ferrihydrite ³	0.25	0.02	56	51.703	1.262	243
Smectite ³	0.37	0.03	5.7	52.945	1.185	243
Dunite ³	0.40	0.03	120.8	53.343	1.172	243
Volcanic Tuff ³	0.45	0.03	149.4	53.945	1.143	243
Tuff + Mg-Sulfate ³	0.51	0.03	196	54.813	1.103	243
Basalt (<63 μm) ¹⁰	0.028	0.005	52.6	49.880	1.387	270
Basalt (63-125 μm) ¹⁰	0.026	0.005	39	49.872	1.387	267
Basalt (125-250 μm) ¹⁰	0.039	0.007	54.3	49.975	1.376	266
Montmorillonite ⁴	0.016	0.003	30	49.795	1.398	270

Table 1. Values derived from modeling in Origin 9.1. $\theta_{\text{avg}} = 0.336 \pm 0.024$ and $\Delta H_{\text{avg}} = 52.783 \pm 1.206$ kJ/mol [3, 4, 10]

Results: When relative humidity data is plotted against temperature, with the lines for Langmuir and BET adsorption plotted over them (Fig. 2), both approaches fit the data well. However, BET fits the entire dataset, while Langmuir fails to fit the points at high humidity and low temperature. When isolating the BET line, the following values yielded the line of best fit: $C = 89.4$, $\Delta H = 52.783$ kJ/mol, $\theta = 0.336$, and specific surface area, $A_s = 9 \text{ E4 m}^2/\text{kg}$ [4] (Fig. 3). These values were put into a numerical model built by Rivera-Valentin [11], which can account for heat and mass transfer as well as adsorption and desorption.

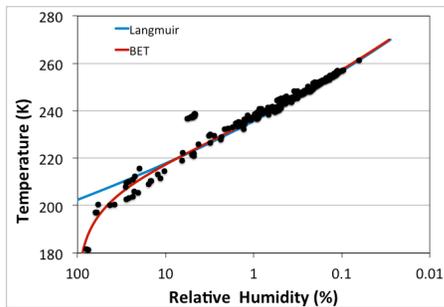


Figure 2. Theoretical Langmuir and BET adsorption lines for JSC Mars 1 plotted with Phoenix TECP data. Langmuir fails to describe all the data, especially at high relative humidities and low temperatures, while BET is an ideal interpretation of the temperature and relative humidity data.

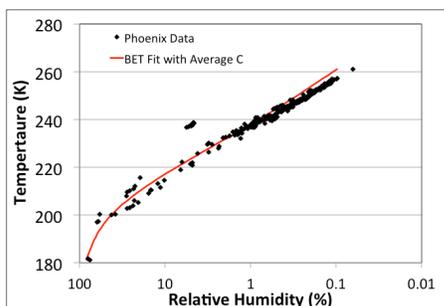


Figure 3. BET adsorption line from model plotted with Phoenix TECP data. When fixing θ_{avg} and ΔH_{avg} , we determined the ideal sticking coefficient for regolith control of atmospheric relative humidity.

The model, which averages the data every $30^\circ L_s$ (56 sols) and includes a temperature profile (depth = 3 m) and a surface coverage profile (depth = 0.01 m, adsorption from the ice table upwards), produced some interesting results. Since ΔH is relatively low, the regolith can easily desorb, which is why we see surface coverage, θ , go to 0 (Fig. 4). In addition, our C is relatively high, so with a high adsorptive capacity, the amount of free water in the atmosphere is not high enough to reach our desired theta. For the case of Phoenix, a material with a lower adsorptive capacity and also probably a higher ΔH that can hold onto and not readily give up water during the summer months is essential.

Future modeling will investigate various mixing ratios of various regolith analogs with lower specific surface areas, as well as the significance of salt concentrations, like perchlorates [1, 2] in the regolith. We know deliquescence of perchlorate salts occurs at the Phoenix landing site and has an impact on the water cycle [12].

Conclusions: While Langmuir fails to describe the relative humidity-temperature relationship, especially

at low temperatures and high humidities, BET can explain metastable accumulation of adsorbed liquid water at the surface of Mars, but in very small quantities ($\theta = 0.336 \approx 2.96 \text{ E-7 kg of H}_2\text{O/m}^2$).

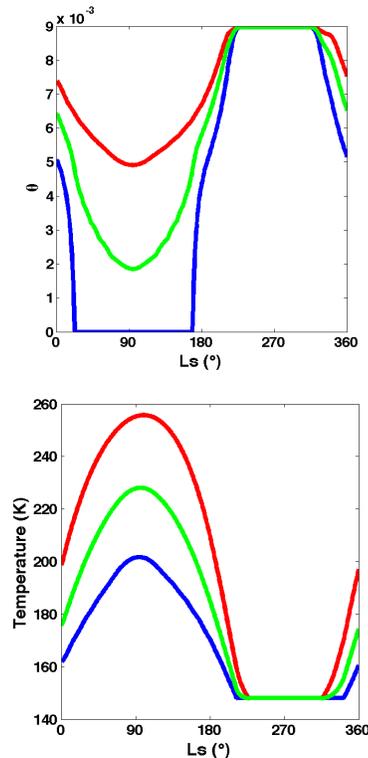


Figure 4. Surface coverage (top) and temperature (bottom) as a function of solar longitude from numerical model. (red = max., green = mean, and blue = min.)

The ideal sticking coefficient by which regolith controls atmospheric relative humidity is $C = 89.4$, suggesting that the ideal regolith for adsorption is a mixture of poor adsorbents (ie. clays) and excellent adsorbents (ie. volcanic tuff). However, from the modeling it is unclear what percentages of various materials are preferential and the effect of salt concentrations in the regolith has not been taken into account.

References: [1] Hecht M. H. et al. (2009) *Science* 325, 64-67. [2] Zent A. P. et al. (2009) *Journal of Geophysical Research (Planets)*. [3] Pommerol et al. (2009) *Icarus* 204(1), 134-136. [4] Chevrier V. et al. (2008) *Icarus* 196 (2), 459-476. [5] Brauner et al. 1938 [6] Poulet F. et al. (2007) *Journal of Geophysical Research*. 112. [7] Jakosky B. M. et al. (2005) *Icarus*. 175, 58-67. [8] Smith, M. D. (2002) *Journal of Geophysical Research*. 107. [9] Beck P. et al. (2010) *J. Geophys. Res.* 115 (10), 1-11. [10] Bryson K. L. et al. (2008) *Icarus* 196, 446-458. [11] Rivera-Valentin (2012) Ph.D. Dissertation, Univ. Arkansas. [12] Nuding et al. (2014) *Icarus*, 243, 420-428.