# Quantifying Water Content and Equilibration Timescale of Wind Tunnel Materials

X. Yu[1], S.M. Hörst[1], C. He[1], N.T. Bridges[2], and D.M. Burr[3] [1]Department of Earth and Planetary Sciences, Johns Hopkins University (xyu33@jhu.edu); [2]Applied Physics Laboratory, Johns Hopkins University; [3]Department of Earth and Planetary Sciences, University of Tennessee

**Introduction**: Aeolian processes are found on many planetary bodies in the Solar System, including Earth, Venus, Mars, Saturn's moon Titan, Triton, Pluto and the comet 67P/Churyumov-Gerasimenko [1]. Both Earth and planetary wind tunnels serve as an effective way to simulate aeolian processes under different planetary parameters, with the robustness of results dependent upon the degree of control of experimental conditions and understanding of the experimental materials [2]. The threshold wind speed needed to initiate saltation is one of these processes that may be investigated experimentally. For example, recent Titan Wind Tunnel (TWT) results show a 50% higher than previously predicted threshold wind speed that is likely caused by the high atmospheric density (5.1 kg/m$^3$) over particle density (radar dark, organics, 400–1500 kg/m$^3$) ratio on Titan compared to Earth (1.2 kg/m$^3$ over 2650 kg/m$^3$ of typical sand) [3].

The threshold wind speed is determined by the balance of gravity, the aerodynamic force, the drag force, and interparticle forces. On Earth, water is relatively abundant and interparticle forces are dominated by cohesion between adsorbed water molecules adsorbed on the surfaces of particles [4]. In contrast, on planetary bodies like Titan, Venus, Mars, and comet 67P, water is low in abundance such that interparticle forces are likely dominated by electrostatic forces (see discussion in [3]), or potentially cohesion between other liquids such as $C_2H_6$ on Titan [5]. Because wind tunnel materials are not commonly dessicated and generally conducted within an atmosphere with some amount of humidity, assessing the contribution of adsorbed water to interparticle force provide a more precise translation of experimental threshold results to planetary environments in which water is largely absent. Toward that end, here we examine the water content and equilibration timescales of some common (and uncommon) wind tunnel materials. This examination is a necessary first step in understanding the effect of water adsorption on threshold wind speed. These materials have been used to simulate saltation on Earth,Titan, Mars and Venus [1, 2, 3] and our results are therefore broadly applicable to a range of planetary conditions.

Prior studies have investigated the effect of water content on threshold wind speed for sand. [6] showed that water content from 0.1% to 0.2% results in a 10% increase in threshold for typical 400 $\mu$m sand particles, and [2] suggested that threshold doubled with 0.3%-0.6% moisture in typical quartz sand compared to dry sand. However, similar data are missing for low density materials, which are needed to simulate the weight of sand on Titan. Here, we extend that prior work to low density materials. Based on this previous work, our hypothesis is that threshold increases by up to 100% under humid conditions. Low density materials are used in the TWT to simulate the lower gravity on Titan (9.8 m/s$^2$ on earth versus 1.4 m/s$^2$ on Titan) and the low density of the Titan sand, inferred to be composed of organics [7]. These low density materials include sieved walnut shells (density 1100 kg/m$^2$) and gas chromatography packing materials (GC). The water content and equilibration timescales of these low density materials have not been previously measured and are the focus of this study. We also measured basalt, quartz sand, and beach sand for comparison.

**Methods and Initial Results**: Table 1 summarizes the materials investigated in this work. With the exception of activated charcoal, iced tea, and instant coffee, the materials used came from the batches in use at the TWT [1, 3]. Given the absence of water on Titan, activated charcoal was included as a non-polar weakly interaction material. Iced tea and instant coffee were included as additional low density materials.

| Material | Density (kg/m$^3$) | Size Range ($\mu$m) |
|---|---|---|
| Basalt | 3000 | 150–1000 (3*) |
| Quartz Sand | 2650 | 106–250 (5) |
| Beach Sand | 2650 | 500–1000 (4) |
| Walnut Shells | 1100 | 125–1000 (6) |
| Activated Charcoal | 400 | 400–841 (1) |
| GC | 350 | 37–175 |
| Iced Tea | 100–200 | N/A |
| Instant Coffee | 100–200 | N/A |

Table 1: Summary of material properties. * indicates the number of size bins.

We determined the water content of the materials through gravimetric measurement. The materials were put in a small aluminum foil boat, weighed using an analytical balance ($m_{wet}$) and, dried for 24 hours in a 120 °C oven. After drying, they were removed from the oven and immediately weighed again ($m_{dry}$). The water content is then given by:

$$u(\%) = \frac{m_{wet} - m_{dry}}{m_{dry}} \times 100\% \qquad (1)$$

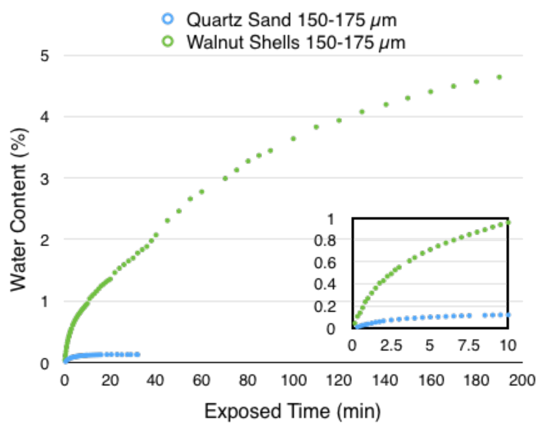


Figure 1: Plot of water content as a function of time, beginning with dehydrated materials. Walnut shells take longer to equilibrate with the atmosphere and achieve a much higher water content.

We also investigated the time required for the material to equilibrate with the ambient atmosphere by continuing to measure the weight (and relative humidity) as a function of time. Figure 1 shows the typical increase in water content as a function of time for quartz sand and walnut shells due to water adsorption. The difference in water adsorption between the two materials is dramatic, with walnut shells taking more than 6 hours to equilibrate and acquire over 5% of water content (at only 20±3% RH), while quartz sand equilibrated in less than half an hour and acquired only 0.05–0.1% water.

Figure 2 summarizes the equilibrium water content for all of the materials we investigated. The materials exhibit a range of water content from ∼0.05% to ∼10.5%. The low equilibrium water content materials include quartz sand, beach sand, and basalt, while high equilibrium water content materials include walnut shells, instant coffee, iced tea, GC and activated charcoal. The low equilibrium water content materials are generally both water insoluble and with low porosity. Materials with high equilibrium water content are either porous (walnut shells and activated charcoal), hydrophilic (walnut shells) or soluble (iced tea and instant coffee). As shown in Figure 2, equilibrium water content does not show any strong dependence on size.

The equilibrium water content varies with relative humidity. Equilibrium water content varies approximately linearly with relative humidity, with $R^2$ values over 0.8, for RH range of 15% to 60%.

**Discussion and Future Work**: The equilibrium water content of terrestrial soil under ambient conditions is 0.2–0.6% and the equilibrium wetting time is 10–50 minutes [8]. However, for the wind tunnel materials used here, especially the low density walnut shells, the equilibrium water content is much higher (5% at RH=20%) and equilibrium timescales are much longer (over 6 hrs).

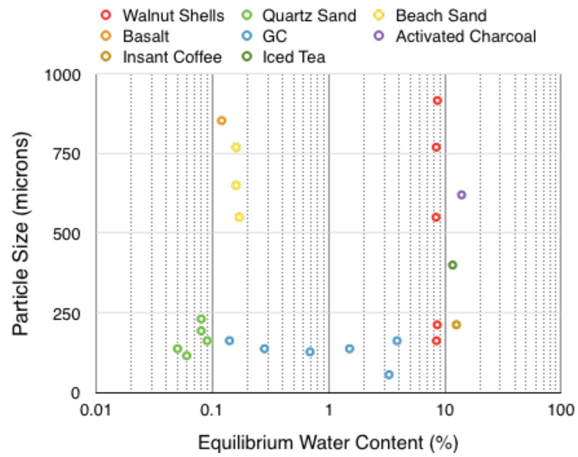


Figure 2: Equilibrium water content of various materials and sizes at RH=58.5±3%.

Threshold wind speed is affected by the surface water rather than the total water content of the materials. Thorough evaluation of the materials therefore requires separation of surface and internal water content to fully understand the effect on threshold velocity. Thermogravimetric analysis could be useful, since surface water released at a lower temperature than internal water. These measurements are currently in progress.

The particularly long equilibration timescale of walnut shells could be used to estimate the effect of moisture content on threshold because it enables walnut shells to be dried and used in a TWT run before they have had time fully equilibrate. Comparison of "wet" and "dry" wind tunnel runs would provide insight into the effect of cohesion on threshold wind speeds. This will allow us to better assess the interparticle force from adsorbed water and thereby better apply the results to future TWT experiments and other planetary conditions.

**References:** [1] D.M. Burr, et al. *Aeolian Research*, 18:205–214, 2015. [2] R Greeley and JD Iversen. *Cambridge Univ, Cambridge*, 1985. [3] D.M. Burr, et al. *Nature*, 517:60–63, 2015. [4] C.M. Neuman. *Boundary-Layer Meteorology*, 108(1):61–89, 2003. [5] R.D. Lorenz. *Icarus*, 230:162–167, 2014. [6] P-Y Belly. Technical report, USACE, 1964. [7] J.W. Barnes, et al. *Icarus*, 195(1):400–414, 2008. [8] S. Ravi, et al. *Sedimentology*, 53(3):597–609, 2006.