THERMAL PROPERTIES OF MARTIAN SOIL, ICE AND MIXTURES.

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Introduction: The materials that are exposed at the surface of Mars or constitute the near-surface layers vary remarkably in different regions on Mars, from almost pure water ice and carbon dioxide ice at the polar caps through an ice-dominated matrix with dust inclusions at high latitudes to loose windblown sediments. Though the thermal properties for the bulk constituents are well known, the thermal conductivity for three-phase mixtures (i.e. silicate grains, ice and gas-filled voids) are not. The effective thermal conductivity can vary over at least 3 orders of magnitude, and depends only weakly on composition, moderately on density/porosity, while the most important parameters are microstructure and pore-filling gas.

Heat conduction through the matrix is limited by the bottle necks at the contact points of single silicate or ice grains. In loose aggregates these contact points provide very little cross section area and thus cause a substantial decrease on the ability to conduct heat. Salts and hydrothermally formed minerals that from duricrusts at the surface (i.e. soil that is hardened by cementation) not only increase the cohesion but at the same extent the thermal conductivity, because both grow with contact area between grains. Interstitial ice would also form preferably at the contact points because surface energy is minimized. Only small amounts of water ice suffice to form relatively large sinter necks between single dust grains, and thereby cause a significant increase in the thermal conductivity. Whenever interstitial ice grows or evaporates with season, the thermal conductivity as well as the thermal inertia, which can be measured from remote, will vary as well.

In addition to solid state heat transport through the matrix, heat is transported by gas. In cold regions where ices are present at least for cold nights or seasons, the pore-filling vapour will also transport latent heat – a process that is very effective in comets, but not taken into account in most thermal models of Martian near surface layers. The relevant thermophysical comet modeling literature [1,2,3] provides valuable theoretical background that should be included in thermal models for Martian near surface layers.

For both forms of heat transport by gas (sensible heat and latent heat), the pore size is important, if the pores are smaller than the mean free path of gas molecules. The ambient pressure at Mars is in a range where the pore size effect is important at least for smaller pores. Therefore, soils of the same composition and porosity may differ considerably in thermal conductivity. TES thermal inertia data show that there is a strong correlation between the maximum observed thermal inertia and topography. With an estimated density (1500 kg m^{-3}, corresponds to 3000 kg m^{-3} at 50% porosity) and specific heat (1000 JK^{-1}kg^{-1}), the measured thermal inertia can be converted into a thermal conductivity (see figure 1). At high elevation, the thermal inertia is limited to much smaller values, because (a) the ambient pressure is lower and (b) wind blow dust particles cannot exceed a certain size limit which is smaller for low pressures.

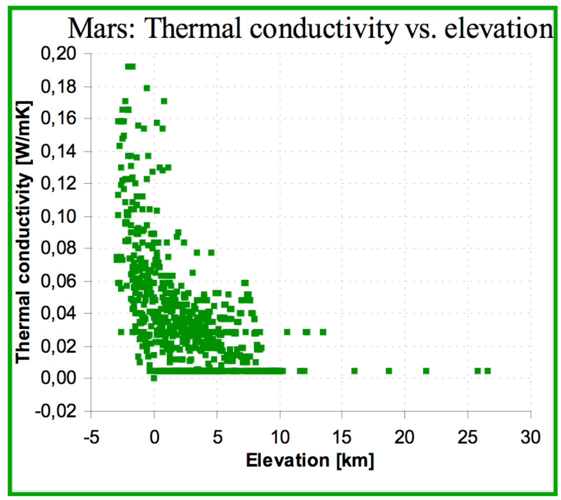

Figure 1: Thermal conductivity (derived from measured thermal inertia) vs. elevation.

Laboratory Measurements: Though returned samples of Martian soil are not (yet) available, laboratory measurements of the thermal properties of artificial samples can provide important data. Furthermore, a returned sample will most probably not have retained its microstructure, and will be removed from its natural environment (ambient pressure, temperature, humidity). The probably best suited method is the LHS (line heat source) technique, which is described in [4], for example. Measured data about porous ice samples at low ambient pressure can be found in [4,5]. Figure 2 shows data measured on coarse loose dunite and on JSC-1 (Mars) soil simulant. Using fine-grained loose samples in a vacuum chamber turned out to be problematic, because the air cannot diffuse fast enough through the sample during evacuation, and creates an overpressure which blows mineral grains into suspension with the remaining air in the chamber, and ultimately reaches the pump, where it can cause serious damage.

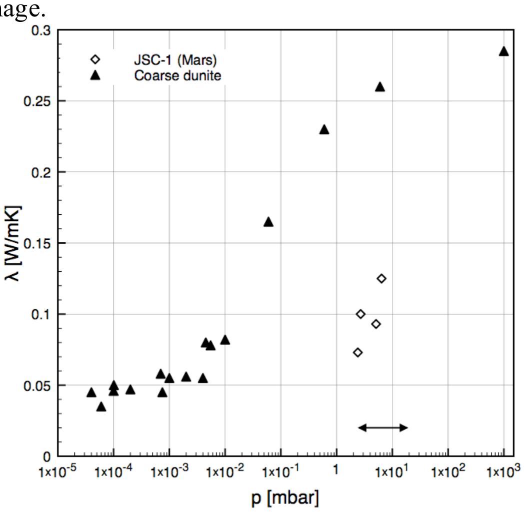

Figure 2: Thermal conductivity measurements of JSC-1 (Mars) soil simulant and a coarse (grain size ~1 mm) dunite sample at different pressures. The difference in thermal conductivity at Martian atmospheric pressure (marked by arrows) is due to the difference in pore size.

In-situ Measurements: No dedicated thermal probe has yet been flown to Mars, but a few have been suggested and studied. The Netlander Mission to Mars, which was unfortunately abandoned in Phase B, included a small instrument called SPICE, which consisted of a 5 cm short, hollow tube that was planned to be inserted into the soil by a robotic arm [6]. A more sophisticated thermal probe is currently studied by ESA and employs a self-penetrating device on a tether to carry the sensors (thermal and others) up to 5 m deep into the subsurface. The penetrator is based on the Mole that was part of the Beagle 2 payload, however in that case not carrying thermal sensors. The basic concept is discussed in [7]. The probably most sophisticated thermal probe for extraterrestrial use is the MUPUS instrument, which is currently on its way to a comet nucleus as part of the ROSETTA Lander PHILAE [8,9]. The MUPUS thermal probe penetrates 32 cm deep into the comet nucleus. It carries 16 sensors along its depth, which can operate as a RTD-type temperature sensor, and can be individually heated and thus perform transient thermal conductivity and diffusivity measurements. Combining the temperature and thermal conductivity profile, heat flows in 16 layers and the energy balance of these layers as a function of time can be computed.

Conclusion:

The treatment of thermal properties of Martian soil deserves more attention that it receives nowadays in many thermophysical models about near-surface layers on Mars. The influence of the microstructure and the pore size is often neglected, while a lot of effort is put on composition and porosity effects, though the latter are clearly less important. Heat transport by pore filling gas and vapour, which is a common feature in all up-to-date coment nucleus models, is also absent in many papers dealing with Mars. The methods, and to some extent even the data, is available and ready to be exploited.

The thermal probes for in-situ measurements as discussed above require very moderate resources, and their geometry and design can be easily adapted to other lander missions. Thermal subsurface measurements on Mars could substantially contribute to the search for water, climate research, global heat flow studies, atmospheric boundary layer studies, and similar fields of research. Future lander missions should, therefore, carry a thermal subsurface probe whenever possible.

References:

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