**THERMAL CONDUCTIVITY AND SPECIFIC HEAT OF THE MOJAVE MARS REGOLITH SIMULANT AND THEIR SENSITIVITY TO AMBIENT CO₂ GAS PRESSURE AND TEMPERATURE.**

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**Introduction:** Measurement of the endogenic heat flow of Mars is one of the InSight mission’s objectives. The Heat Flow and Physical Properties Package (HP³), deployed from the InSight lander in February 2019, is expected to measure in-situ temperature and thermal conductivity of the Mars regolith at multiple depths down to 5 m. Heat flow is then obtained as the product of the thermal gradient and the thermal conductivity of the regolith depth interval penetrated [1]. Regolith below 3-m depth is expected to be beyond the influence of the insolation-induced, seasonal thermal fluctuation at the landing site [2]. Thermal measurements made in that depth range should yield the most reliable determination of the endogenic heat flow.

Measurements from depths shallower than 3 m would also be useful in constraining the surface heat balance between the radiative and conductive flux at the landing site via mathematical modeling. Such models may need to account for the sensitivity of the regolith thermal properties to the ambient CO₂ pressure and temperature. At the landing site, atmospheric CO₂ pressure is expected to vary seasonally from 600 to 1000 Pa [3]. Surface temperature varies diurnally from 170 K to 290 K [4]. Previous laboratory measurements on lunar regolith samples, returned by the Apollo missions, and other particulate materials [5-8] indicate that thermal properties of Mars’ shallow regolith may fluctuate diurnally and seasonally with large enough amplitudes to significantly affect the heat flow through it in the observed pressure and temperature ranges.

In order to further quantify the possible effects of temperature and atmospheric pressure variations on Mars regolith, we carried out a series of thermal conductivity and volumetric heat capacity measurements on the Mojave Mars Simulant (MMS) [9] in a CO₂ gas-filled, thermal vacuum chamber. Here we report the outcome of the experiments.

**Measurement Methodologies:** The so-called ‘needle probe’ (aka. ‘hot wire’) method [10] was used for the thermal conductivity measurements. A probe of 10-cm length and 2.4-mm diameter, containing a thermistor at its mid-point and an electric heater wire along its length, was inserted into the simulant. The heater was activated for 5 minutes, and temperature of the probe was monitored during that time. This methodology has been used widely for in-situ measurements on Earth’s soil and seafloor sediment. In a typical terrestrial application, the probe temperature, after a few tens of seconds of heating, increases linearly with the natural logarithm of the time. Then, the thermal conductivity is obtained from the slope of the temperature-versus-ln(time) plot. However, on the surface of a planet with much thinner atmosphere, such a data plot would be curved due to the fact that the thermal conductivity of the regolith can be 2 orders of magnitude lower than that of the Earth’s soil. Therefore, the data reduction methodology must be modified accordingly [8].

The measurement of volumetric heat capacity used the dual-probe heat pulse (DPHP) method [11]. The probe used for the measurement, often referred to as a ‘thermal diffusivity probe’, consists of a pair of needles, one containing a thermistor at its mid-point and the other containing a heater wire. Both needles were 3-cm long and 1.3-mm diameter, separated by 6 mm (Fig. 1). The heater was turned on for 2.5 minutes. The thermistor needle gradually warmed up as the heat arrived from the other needle, but cooled off after the heater was shut off. The timing and the magnitude of the temperature peak yielded the thermal diffusivity and the volumetric heat capacity, respectively. Multiplication of the two also yields thermal conductivity.

The DPHP method is also widely used for in-situ measurements on terrestrial soil with a much shorter duration of heating (30 seconds or less). For the present study, the longer heating time was necessary due to the low thermal conductivity of the samples in the low atmospheric pressures. Because of the long-duration of heating, the axial heat loss of the needle and the thermal shorting between the two needles significantly affected the outcome of each measurement. The determination of volumetric heat capacity of the samples required three-dimensional numerical simulation of each heating experiment (Fig. 1).

The Mojave simulant was held in a one-gallon (3.8-L) bin and vibratory compacted. Then, the two probes were inserted into the simulant ~5-cm apart. The whole assembly was placed in a thermal vacuum chamber of 0.7 m x 0.7 m x 0.7 m. Finally, the chamber was pumped down and filled with CO₂ gas. A series of side-by-side measurements by the two probes were carried out for combination of 5 CO₂ pressures of 200, 400, 600, 800, and 1,000 Pa and 2 temperatures of (~240 and ~300 K). Two batches of MMS simulant,
one more compacted (bulk density of 1660 kg/m³) than the other (1540 kg/m³), were tested.

**Experimental Results:** Figure 2 plots the thermal conductivity values against CO₂ pressures for the two batches of simulant for the low and the high temperatures. Overall, the high-density simulant yielded greater thermal conductivity values for the same pressure range. The difference between the two batches of simulant is more pronounced at lower pressures. The temperature differences have much less effect on the thermal conductivities. From 600 Pa to 1000 Pa, the thermal conductivity values increased by ~35%. Such change in thermal conductivity should be detectable by HP³ by periodically repeating thermal conductivity measurements throughout the duration of the mission.

Figure 3 plots the specific heat (volumetric heat capacity / density) values against the temperatures. CO₂ gas pressure has little effect on the specific heat, because the mass of the gas is negligible compared to that of the regolith grains. From ~240 K to ~300 K, specific heat of the simulant increased by ~20%.

For comparison, the trend for the lunar regolith samples from the Apollo 14 site [5] is also shown as the dashed line in Fig. 3. The specific heat values for the MMS simulant are 20 to 30 J/(kg·K) lower for a given temperature. This is probably due to the difference in mineralogical composition between the two.

**Conclusions:** The pressure sensitivity of the thermal conductivity and the temperature sensitivity of the specific heat of the simulant suggest that they may have significant influence on the heat flux through the shallow subsurface regolith of the InSight landing site. The pressure-effect on the conductivity may be detectable by repeating measurements periodically. Analyses on the heat flux through the shallow subsurface regolith should account for these effects.

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