ESTIMATION OF SOIL THERMAL CONDUCTIVITY FROM A MARS MICROPROBE-TYPE PENETRATOR. M. L. Urquhart, *Caltech/Jet Propulsion Laboratory, Pasadena, CA 91109, USA, (urquhart@cythera.jpl.nasa.gov)*, S. E. Smrekar, *Jet Propulsion Laboratory, Pasadena, CA 91109, USA.*

Introduction

Deep Space 2 (DS2) was designed to be the first planetary penetrator mission. The primary purpose of DS2 was to test new technologies for use on future spacecraft [1]. Although the two Mars microprobes were lost in December 1999, much of the instrumentation and other technology may still be useful on future missions. The soil conductivity experiment, for example, may be applicable to future penetrators sent to Mars, asteroids, comets, or natural satellites. We have conducted a series of laboratory tests to determine how well the thermal conductivity of a particulate material can be determined from the rate of cooling of an embedded probe.

The Thermal Conductivity Experiment

Typically *in situ* thermal conductivity measurements are made using an active heating approach [2]. Such an experiment requires either a large power source to heat the entire penetrator, or deployment and thermal isolation of a smaller needle. Instead, this experiment relies upon the cooling of the penetrator after impact to determine the thermal conductivity of the soil. Although this method is not as accurate as those using a calibrated heat pulse, it is very efficient in terms of cost, power, mass, and complexity.

In the regoliths of Mars and other bodies with low or no atmospheric pressure, thermal conductivity is a function of the physical properties of the soil such as grain size and particle cementation, and thus can be used to better understand geologic processes. For the polar layered terrains of Mars, were DS2 was to land, data indicate the presence of dust at the surface, but models predict ice [3]. The presence of significant slopes in the polar layered terrain suggest that cementation of soil grains may be occurring [4]. Cemented grains have a thermal conductivity similar to solid ice or rock [5]. The expected range of thermal conductivity at the DS2 landing site therefore spans 3 orders of magnitude. Thus this type of experiment can yield information on grain size, cementation of grains, and volatile content. For asteroids and possibly comets, the possible range of thermal conductivities is even larger. Thermal conductivities of uncemented dust or sand sized silicate particulates will be an order of magnitude lower on airless planetary bodies than on Mars [6].

Instrument Description

The Mars microprobes consisted of a aftbody which was designed to remain at the surface of Mars, and a 10.5 cm long forebody penetrator with several instruments including temperature sensors in the nose and tail. Our laboratory probe is an engineering model of the forebody and is identical to the forebodies of the Mars microprobes [1] with a few exceptions. For example, the drill stem assembly from the sample collection experiment was omitted in the laboratory probes, and small steel rings were added on the nose and tail to allow the probed to be pulled into a tank of simulated soil on a pulley system.

Laboratory Quench Tests

Test were designed to simulate the conditions anticipated at the landing site on the Mars layered terrain [1], including pressures of 5-10 Torr and different grain sizes. Laboratory tests are conducted in a 60 cm diameter by 40 cm deep cylindrical tank. Test were done at room temperature, as thermal conductivity is weakly dependent on temperature for the temperature range appropriate for Earth or Mars, especially in the presence of an atmosphere [6]. The tank is filled with a simulated soil composed of glass beads of known grain size. Glass beads were chosen because of their cleanliness, uniformity, and past experiments that estimated their thermal conductivity at Mars pressures [7,8,9]. Prior to emplacement in the tank containing the glass beads, the probe is heated between about 40 and 80 degrees C above the temperature of the beads. This is similar to the temperature difference expected between one of the Mars microprobes and the surrounding soil. Both the tank and the probe's heating jacket are kept in a vacuum chamber. Before each test, the pressure in the chamber is pumped down to approximately 0.02 Torr. Water vapor is removed from the system by maintaining the pressure at approximately 0.02 Torr for two to three days. CO_2 is then added to bring the pressure up to the desired level prior to the start of the quench test. In addition to the temperature sensors in the nose and tail of the probe, several temperature sensors were placed in the tank at varying distances from the probe so that a background temperature is known throughout the experiment.

We have acquired data on the cooling of the probe for grain sizes of 650-900 microns (sand-sized particles) and 40-70 microns (dust-sized particles). For each grain size, tests were conducted at vacuum chamber pressures of both 5 and 10 Torr. We have conducted one test at low vacuum, and intend to do more to evaluate the utility of the probes for measuring thermal conductivity in the regoliths of solar system objects such as asteroids and comets. Each test was run over a period of several days to insure that the probes had time to equilibrate with the soil simulant.

Thermal Model and Comparison with Data

The cooling of our probe is modeled using the Systems Improved Numerical Differencing Analyzer (SINDA) which is a commercial software package designed for the solution of diffusion-type equations [10]. We have constructed a detailed model of the specific geometry and material properties of the probe for use with the SINDA software. Our model also includes the physical properties of the particulate material surrounding the probe.

Figure 1 shows data from one test with the sand-sized grains and a pressure of 10 Torr compared with our model results for emplacement in dust, sand, and ice or a cemented material. The behavior of the model is strongly dependent upon the thermal conductivity of the particulate medium in which the probe is embedded. For a thermal conductivity of k=0.01 W/m-K appropriate to dust, the probe in both the model and the tests took more than a day to come to equilibrium with the soil, whereas for an ice or salt cemented regolith with a thermal conductivity closer to 1 W/m-K, the probe reaches equilibrium with the soil in less than a few hours. For a sandy medium without cementation, the thermal conductivity is intermediate between dust and a cemented medium, and both the model and the actual probe cool to the ambient temperature of the particulates in less than 10 hours.

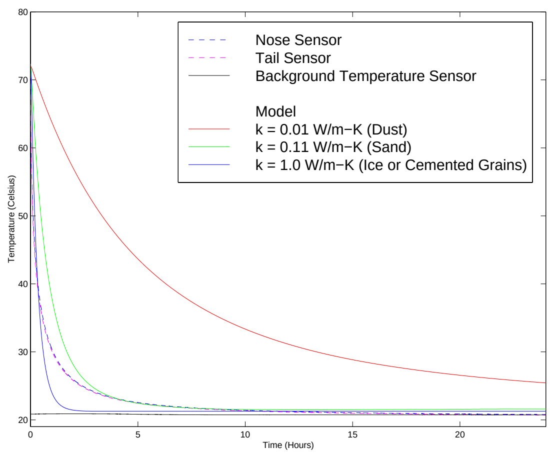

Figure 1: Comparison of model results with probe nose, probe tail, and background temperature sensor data over a 24 hour period from a test with 650-900 micron grains and a pressure of 10 Torr. The probe was initially heated to a temperature of 72 degrees C, and the temperature of the glass beads was 21 degrees C. The models shown for comparison are for mediums with thermal conductivities appropriate to dust (k=0.01 W/m-K), the sand-sized grains actually used in the test (k=0.11 W/m-K), and an ice or salt cemented medium (k=1.0 W/m-K). Nose and tail temperatures for both the actual probe and each of the models are too close to distinguish from one another on this figure.

In general, our model agrees reasonably well with laboratory data on the cooling of the probe in the quench tests. However, during the first few hours of each test, the laboratory probe cools faster than does our model probe. We are in the process of examining possible reasons for this discrepancy. We have refined our model of the probe geometry to include the steel rings which were attached to the laboratory probe for use with the cabling system. More such refinements regarding the cabling system and small irregularities on the surface of the probe may be necessary to properly model the probe's behavior immediately after emplacement in the beads. Overall, however, this discrepancy does not greatly impact the estimate of thermal conductivity from the probe. Mediums composed of dust and sand-sized particulates will be easily distinguishable from one another, as should be an ice or salt cemented medium.

Needle Probe Results

In addition to the quench tests, we used a needle probe as an independent means to determine the thermal conductivity of the glass beads at different pressures. Needle probe tests for the beads at with a 40-70 micron grain size are in excellent agreement with the laboratory measurements of thermal conductivity under Mars conditions made by Presley and Christensen, 1997 [8]. Our needle probe test for the larger grains (650-900 microns) do not agree as closely with those of Presley and Christensen, 1997 [8]. We are continuing our tests and investigating possible reasons for the differences between our measurements. For our probe cooling model, we have continued to use the thermal conductivity measurements of Presley and Christensen [8].

Conclusions

The thermal conductivity experiment which was carried on the Mars microprobes may be useful to future planetary missions, despite the loss of Deep Space 2. Comparison of our laboratory data and thermal model shows that the passive cooling of a heated probe can allow for the thermal conductivity of the surrounding medium to be estimated with sufficient precision to determine if the medium is composed of uncemented dust or sand sized particles, or if a significant amount of cementing ice or salt is present.

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