LABORATORY MEASUREMENTS OF THERMAL CONDUCTIVITY OF PARTICULATE MATERIALS UNDER MARTIAN ATMOSPHERIC PRESSURES *M.A. Presley and P.R. Christensen, Dept. of Geology, Arizona State University, Tempe AZ 85287*

Overview: This is a presentation of the first comprehensive set of measurements of the dependence of thermal conductivity on particle size for particulate materials under martian atmospheric pressures. These values differ significantly from previous measurements, but are consistent with estimates of particle sizes for both atmospheric dust and low albedo surficial units on Mars.

Introduction: The mean particle diameters of surficial units on Mars have been estimated from previous thermal conductivity measurements of particulate materials and thermal inertia determinations from the Mariner 9 Infrared Radiometer and the Viking Infrared Thermal Mapper [1,2]. Several studies [*e.g.*, 2,3,4] have used these estimates to characterize the surficial units and infer their depositional histories.

Previous experiments have shown that particle size significantly affects the thermal conductivity under low pressures, particularly under the range of pressures typical of the martian surface [*e.g.*, 5,6]. The transfer of thermal energy due to collisions of gas molecules is the predominant mechanism of thermal conductivity in porous systems not under vacuum [6]. At martian surface pressures the mean free path of the gas molecules is greater than the effective distance over which conduction takes place between the particles, which is approximately one-sixth the particle diameter [7]. Gas molecules are more likely to collide with the solid particles than they are with each other. The average heat transfer distance between particles, which is related to particle size [8], shape and packing, thus determines how fast heat will flow through a particulate material.

Relatively few thermal conductivity measurements were available to derive the one-to-one correspondence of thermal inertia to mean particle diameter [1]. The samples used were often characterized by fairly wide ranges of particle sizes with little information about the possible distribution of sizes within those ranges [5]. Some investigators used spherical glass beads, and others used angular grains of quartz, basalt, and granite. All thermal conductivities were measured in a nitrogen-oxygen atmosphere (air) at room temperature. Temperature effects are expected to be minimal [9]. Thermal conductivities measured in a carbon-dioxide atmosphere are, however, consistently smaller than those measured in air by a small but significant amount (~7%) [10,11]. No comprehensive studies have been carried out at martian pressures on factors other than grain size that affect the interparticle pore dimensions, such as particle shape, bimodal or polymodal mixtures of grain sizes and formation of salt cements (crust) between grains.

Experimental: To address these limitations and to provide a more comprehensive set of thermal conductivities vs. particle size, a line-heat source apparatus, similar to that of Cremers [12], was assembled to provide a means of measuring the thermal conductivity of particulate samples. Initial measurements concentrated on the dependence of the thermal conductivity on particle size. For this purpose spherical glass beads were precision sieved into relatively small size ranges and thoroughly cleaned. All size ranges have less than a 10 μm spread, except for the two largest samples (500-520 μm and 250-275 μm) and the smallest sample (11 μm and less), and several samples have a spread of less than 5 μm. The total range of sizes that were investigated is 10 μm to 800 μm.

Results: The dependence of thermal conductivity on particle size thus determined differs significantly from previous estimates. Palluconi and Kieffer [13] asserted that thermal inertias for the surface of Mars range from 1.5 IU (1 IU = x 10^{-3} cal / $cm^2 s^{1/2} K$ = 41.84 J / $m^2 s^{1/2} K$) to 15 IU, with peak occurrences at 2.5 IU and 6.5 IU. If the product of density and specific heat is assumed to be 0.24 cal / $cm^3 K$ (5.7 x 10^4 J / $m^3 K$) and the pressure is assumed to be 6 mbar, then previous estimates [1] indicate these values correspond to 10 μm for 1.5 IU, 3.5 mm for 15 IU, 30 μm for 2.5 IU and 290 μm for 6.5 IU. The values obtained from this study, however, indicate the correspondance is approximately 1 μm for 1.5 IU, 10 μm for 2.5 IU, and 450 μm for 6.5 IU. Extapolation beyond 800 μm is imprecise, but implies that 15 IU corresponds to particle sizes greater than 5 mm, and possibly even greater than 1 cm.

These values are consistent with other evidence. The low thermal inertia values correspond with high albedo surficial units, commonly thought to be dust deposits from global dust storms [*e.g.*, 14]. Early estimates of the size distribution for atmospheric dust is 1-10 μm [15]. Later estimates indicate an even smaller size distribution [16]. These values are consistent with values of 10 μm for 2.5 IU and 1 μm for 1.5 IU. The high thermal inertias correspond with low albedo units, commonly thought to be sand-sized deposits [*e.g.*, 17]. Edgett and Christensen [4] argue that eolian physics indicates the average particle size on martian dunes is probably larger than 430 μm. This is consistent with a particle size of 450 μm for 6.5 IU.

Other attributes aside from particle size also affect the pore size, and therefore the thermal conductivity. Some of these effects are also being investigated. 25-30 μm glass beads with a bulk density of 1.6 g/cm^3 have consistently higher thermal conductivities over the entire range of pressures investigated than glass beads of the same size with a bulk density of 1.4 g/cm^3. This is expected since higher density means a greater amount of solid material within the same volume, and is consistent with the results of experiments under vacuum conditions by Fountain and West [9].

25-30 μm crushed quartz (0.75 g/cm^3) has consistently lower thermal conductivites than 25-30 μm (1.4 g/cm^3) and 15.6-20 μm (1.2 g/cm^3) glass beads. The angular shape of the grains leads to more spatious packing as indicated by the densities of the samples. The lower density of the quartz may be the predominant factor when comparing with the 25-30 μm and the 15.6-20 μm glass beads. The density of the quartz is lower than the 11-15.6 μm (0.9 g/cm^3) glass beads, however, and yet the thermal conductivity of the quartz is consistently higher than that of this size range. These examples indicate that the density, or packing, of the material can have a significant effect on the thermal conductivity in addition to the affects of particle size.

A previous study [7] of a bimodal mixture of particle sizes indicated that such a mixture will exhibit higher conductivities than either size fraction alone at pressures greater than 10 torr. Studies are now under way to determine how the ratio of the two size fractions affects this result, and to determine if this is ever an effect at the lower pressures more typical of the martian surface. The results of these studies will also be presented.

Summary: These experiments have provided an improved estimation of the correspondence of particle size to thermal conductivity at various pressures of carbon dioxide typical of the martian surface. Comparison of samples with different densities and particle shape provide information on how these attributes can affect the determination of mean particle sizes for the surficial units. Additional measurements on the effect of heterogeneous mixtures and salt formation between grains will provide additional information that is necessary when using thermal data to characterize surficial deposits.

References: [1] Kieffer *et al.* (1973). *J. Geophys. Res.* **78**, 4291-4312. [2] Kieffer *et al.* (1981). *Proc. Lunar Planet. Conf.* **12B**, 1395-1417. [3] Presley and Arvidson (1988). *Icarus* **75**, 499-517. [4] Edgett and Christensen (1991). *J. Geophys. Res.* **96** 22765-22776. [5] Wechsler and Glaser (1965). *Icarus* **4**, 335-352. [6] Wechsler *et al.* (1972). *Thermal characteristics of the moon*, pp. 215-241. [7] Woodside and Messmer (1961). *J. Appl. Phys.* **32**, 1688-1699. [8] Schotte (1960). *AIChE Journal* **6**, 63-67. [9] Fountain and West (1970). *J. Geophys. Res.* **75**, 4063-4069. [10] Kistler (1935). *J. Phys. Chem.* **39**, 79-85. [11] Prins *et al.* (1950). *Physica* **16**, 379-380. [12] Cremers (1971). *Rev. Sci. Instr.* **42**, 1694-1696. [13] Palluconi and Kieffer (1981). *Icarus* **45**, 415-426. [14] Christensen (1982). *J. Geophys. Res.* **87**, 9985-9998. [15] Toon et al. (1977) Icarus 30, 663-696. [16] Haberle and Jakosky (1991). Icarus 90, 187-204. [17] Thomas (1981). *Icarus* **48**, 76-90.