THE EFFECT OF BIMODAL AND POLYMODAL MIXTURES OF PARTICLE SIZES ON
THE THERMAL CONDUCTIVITY OF PARTICULATE MATERIALS UNDER MARTIAN
ATMOSPHERIC PRESSURES

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Overview: New measurements of the effect of bimodal and polymodal mixtures on the thermal conductivity of particulate materials under martian atmospheric pressures are presented and discussed. The thermal conductivity of a particulate material containing a mixture of different particle sizes is the same as the thermal conductivity that the material would have if it were composed entirely of the largest particle sizes contained within that material.

Introduction: As discussed in the preceding abstract [1], previous experiments [2] have determined a quantitative relationship between the thermal conductivity of particulate materials and the particle size of the material and atmospheric pressure. This relationship can be used to characterize the surficial units on Mars and infer their nature and possible origin. Particle size and atmospheric pressure are not the only parameters that can affect the thermal conductivity of surface deposits under martian conditions, however. Particle shape, bulk density, and bimodal or polymodal mixtures of different particle sizes, will also affect the average heat transfer distance between particles, and therefore the thermal conductivity of the deposit. No comprehensive studies have previously been carried out at martian pressures to determine how these other parameters affect thermal conductivity.

Experimental: To address this limitation, a line-heat source apparatus [2,3,4] was used for a preliminary investigation of these parameters. In this second abstract, the effect of particle size mixtures are discussed. Two synthetic bimodal mixtures were prepared for this study [4] and two natural polymodal mixtures were also examined. The synthetic samples are composed of different proportions of < 11 μm glass beads (5 and 9 weight percent, respectively) mixed with 250-275 μm glass beads. The natural samples are from basaltic dune sands. One was a well-sorted, fine-grained sample (mean and median particle size: 2.75 μm, or 150 μm). The other was a poorly-sorted, coarse-grained sample (mean particle size: 0.33 μm, or 800 μm; median particle size: 0.10 μm, or 930 μm).

Results: The thermal conductivities of two mixtures of different proportions of < 11 μm glass beads with 250-275 μm glass beads are compared to those of 100% 250-275 μm glass beads and 100% < 11 μm glass beads, over a range of atmospheric pressures, from 0.5 to 100 torr. There is no significant difference between the thermal conductivities of the mixtures and those for 100% 250-275 μm glass beads, within experimental error [4]. This result implies that mixtures of different size particles will have the same bulk thermal conductivity as a pure sample of the largest particle size.

These results, however, do not match those obtained by Woodside and Messmer [5], where the bulk thermal conductivity of the mixture was clearly enhanced over that of either pure end member at pressures greater than 10 torr. One possible explanation is that this enhancement occurs only for certain proportions of the two end members, which have not yet been analyzed in this study. Woodside and Messmer [5] failed to relate the exact proportions of their mixture. Rather, they stated only that the smaller particles filled the pores of the larger particles as much as possible.

Woodside and Messmer [5] listed the porosity of their pure 74–104 μm sample as 59%, the porosity of their pure 590–840 μm sample as 33–36%, and the porosity of the mixture of the two as 18%. Their mixture is more tightly packed relative to their end member materials. As discussed in the previous abstract [1], an increase in the density will result in an increase in the thermal conductivity. The enhanced thermal conductivity is therefore more likely to be the result of the significantly higher density of the mixture, rather than due to simply mixing...
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different particle sizes. Like the end member samples of Woodside and Messmer [5], the mixtures in this study were loosely packed.

The thermal conductivities of a sample of coarse, poorly sorted basaltic dune sand (CD-01) are compared to those of 700–710 μm, 500–520 μm, and 250–275 μm glass beads, over a range of atmospheric pressures, from 0.5 torr to 100 torr. There is a great deal of scatter in the data for the higher conductivity values. Some of this scatter is expected because the sand contains particles as large as 2.5 mm and the current laboratory set up is not well suited to measure the thermal conductivity of particles greater than 1 mm [4]. The scatter in the data at other relatively high thermal conductivity values is due to higher error in the precision of these values [2,4].

The trends in the data are clear enough, despite the scatter, to validate the conclusions reached in the study of bimodal particle size mixtures of glass beads. The mean size of CD-01 is equal 0.33 φ, or 800 μm, and the range of particle sizes is < 4φ to ~1.5φ, or < 60 μm to 2.8 mm. The thermal conductivity values of CD-01 are difficult to distinguish from those of the 710–900 μm sample within the precision error, which is approximately 20% at these higher thermal conductivities. Nevertheless, for atmospheric pressures of 5 torr and higher, the thermal conductivity values of CD-01 are consistently higher than those for the 710–900 μm sample by 2-23%, with an average increase of ~10%. For atmospheric pressures of 2 torr and higher, the thermal conductivities of CD-01 are also consistently higher than the 500-520 μm sample by 17-33%, with an average increase of ~25%.

Although 50% of CD-01 is composed of particles smaller than 500 μm, there are no thermal conductivities of CD-01 that match the lower thermal conductivity values of the smaller particle sizes. This result indicates that the thermal conductivity of a sample matches the thermal conductivities of its largest particle sizes, and will not provide any information on particles smaller than that, even if the smaller particles make up a significant (~50%) part of the sample.

The thermal conductivities of a sample of fine, well sorted basaltic dune sand (CD-04) are compared to those of 160–180 μm, 149–160 μm, and 90–100 μm glass beads, over a range of atmospheric pressures, from 0.5 torr to 100 torr. The thermal conductivities of CD-04 are difficult to distinguish from those of either the 160–180 μm sample, or the 149–160 μm sample within the error of precision, which is 10–15% at these particle sizes. Nonetheless, for atmospheric pressures of 2 torr and higher the thermal conductivity values of CD-04 are consistently higher than those values for the 160–180 μm sample by 1–10%, with an average ~5% increase, and consistently higher than those values for the 149–160 μm sample by 5–15%, with an average ~10% increase. These results are manifested even though particles larger than 180 μm make up less than 2% of the sample [4], and even though particles smaller than 88 μm make up almost 25% of the sample. If fact, the thermal conductivity values of CD-04 are ~25% larger than those for the 90–100 μm glass beads, even though that size range is included in the 3φ size range that composes ~75% of the sample. Again this implies, that thermal conductivity values reflect the larger particles in the sample and say nothing about the distribution of smaller grain sizes within the sample.

Summary: Mixtures of different size particles will have the same bulk thermal conductivity as a pure sample of the largest particle size. Additional measurements are needed to validate this conclusion. Several more bimodal proportions should be examined, especially those in which the larger particle size is clearly in the minority. An attempt to duplicate the results of Woodside and Messmer [5] should also be made, as such a result may be useful in distinguishing exhumed and compacted deposits from freshly laid materials.