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Thermal conductivity measurement of powdered material under vacuum condition

Naoya Sakatani[1*], Kazunori Ogawa[2], Yuichi Iijima[2], Satoshi Tanaka[2]

[1]Titech, [2]ISAS

The heat flow measurement on the planetary surfaces is one of the methods to probe the thermal condition of the planetary interior. The planetary thermal condition such as the bulk amount of the radioisotope produces the surface heat flow, which is measured by the product of the thermal conductivity and the temperature gradient. The surfaces of terrestrial planets are covered with the regolith, but the mechanism of heat transfer through powdered materials is much complicated because various parameters are concerned in the thermal conductivity. Understanding of the mechanism and construction of theoretical models of thermal conduction in the powdered materials are necessary to determine the heat flow value accurately. On the other hand, for future lunar landing mission, thermal control modules are under development in several institutes to protect observation instruments from the severe thermal environment on the Moon. Understanding of the thermal property of the surface materials is required for the thermal design and validation tests of these instruments.
Past studies revealed that the thermal conductivity of powdered materials change with the gas pressure, the particle size and temperature. However, comprehensive understandings including the size distribution and surface textures of the particles is not enough. It is also suggested that the measurement depth (i.e. compaction of particles) can affect to bulk conductivity. Theoretical examinations of these effects are carried out by Halajian and Reichman (1969), but experimental studies have not been done. The objective of this study is to understand systematically the mechanism of the thermal conduction of powdered materials, especially under vacuum condition, by experimental methods.
We measured the thermal conductivity of glass beads at several depths (1, 5, 15, 30 cm) with varying the particle size in 58 to 855 microns diameter to investigate the particle size and compaction effects of powdered materials. For the investigation of the dependency on temperature, the liquid nitrogen was used to vary the temperature of glass beads in -140 to 20 degC. As a result, the thermal conductivity appeared in proportional relation with the particle size at any depth, which results are consistent with previous studies. Thermal conductivities of all sizes of the beads increased with increasing depth, suggesting the compaction effect of the beads. The experiments for the temperature dependency made different result with the measurement depth. At the shallower points, thermal conductivity decreased with decreasing temperature, which results are consistent with previous studies. On the other hand, at deeper points, thermal conductivity increased with decreasing temperature.
All experimental data was compared to the theoretical model derived by Halajian and Reichman (1969). It was found that this model does not describe well the dependency of temperature because temperature dependency of the thermal conductivity of the glass material is not considered. We modified the equation to include the temperature effect on the glass material conductivity, and finally this model was agreeable to the experimental data except for the results of the deeper points.