THERMAL CONDUCTIVITY OF GLASS BEADS AS A MODEL MATERIAL OF REGOLITH.

N. Sakatani[1], K. Ogawa[1], Y. Iijima[1], R. Honda[2], and S. Tanaka[1]. [1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Kanagawa, 252-5210, Japan (sakatani@planeta.sci.isas.jaxa.jp) [2]Kochi University, 2-5-1 Akebono-cho, Kochi, 780-8520, Japan.

Introduction: Terrestrial planets, sattelites, and asteroids are covered with regolith. Thermal behavior of the regolith is important for understanding the thermal state and history of these bodies. Crustal heat flow is estimated by a product of thermal conductivity and temperature gradient of the surface regolith for inference of present thermal state [1]. The regolith layer behaves as heat insulating layer due to its low thermal conductivity, which affects their thermal evolution especially for small bodies [2]. Knowledge of the heat transfer mechanism in the powder materials is required to evaluate the thermal conductivity value of the surface regolith.

The thermal conductivity of powder materials under vacuum consists of two contributions: conduction within the solid particles and across interparticle contacts (solid conductivity) and thermal radiation through void spaces between particle surfaces (named radiative conductivity). In general, the effective thermal conductivity is represented as the sum of these contributions; $k_{eff} = k_{solid} + k_{rad}$ [3]. Each term should be measured and estimated individually in order to understand well the heat transfer mechanism and construct a model of the effective thermal conductivity.

Watson [4] expressed the effective thermal conductivity as $k_{eff} = A + BT^3$, where T is temperature, and A and B are constants independent of the temperature. The first term represents the solid conductivity and the second represents the radiative one. When the thermal conductivity is measured as a function of temperature, the solid and radiative coefficients A and B can be detemined by fitting the equation to experimental data. In this way, the effective thermal conductivity is devided into the solid and radiative conductivities.

Watson [4] and Merrill [5] measured thermal conductivity of several size of glass beads in several temperature conditions. They investigated variation of the solid and radiative conductivities with particle size. As a result, they reported that the solid conductivity decreases and the radiative conductivity increases with the particle size. However, their samples had wide range of porosity, 27-53% in Watson's glass beads and 38-50% in Merrill's ones, to which the thermal conductivity is sensitive [6]. This makes rather big error in results.

In this study, we investigated the thermal conductivity of several sizes of glass beads as a function of temperature with well-controlled constant porosity. In order to control the porosity to be contant, it is convenient to use a sample which consists of uniform spheres and has narrow size distribution. We used glass beads as a model material. The solid and radiative conductivities were estimated as a function of the particle size, independent of the porosity.

Table 1: Glass beads samples.

Particle Size (μm)	Bulk Density (kg/m^3)	Porosity
53-63	1450	0.42
90-106	1450	0.42
355-425	1450	0.42
425-500	1480	0.40
710-1000	1450	0.42

Experiments: We measured the thermal conductivity of glass beads of five sizes in 53 to 1000 μm (Table 1) with changing temperature under vacuum. All samples had almost the same porosity 42%.

The thermal conductivity was measured by the line heat source method [7]. The sensor consists of a nichrome line heater providing heat into the sample and a K-type thermocouple measuring temperature of the heater. The thermal conductivity is estimated from the temperature increase rate of the heater, as $k = q/4\pi s$, where k is the thermal conductivity of the medium, q is heat generation on the heater per unit length, and s is the slope of linear regime in the plot of temperature rise vs. natural logarithm of time after input of the power into the heater. The measurement error of the thermal conductivity was estimated to be less than 10%.

The sample was filled in a sample container with the sensor. The top surface of the sample was set at 1 cm above the heater. The container was placed in a thermostatic vacuum chamber. The sample was evacuated to 10^{-2} Pa. The temperature was controlled from -25 to 50 degC by a step of 25 degrees.

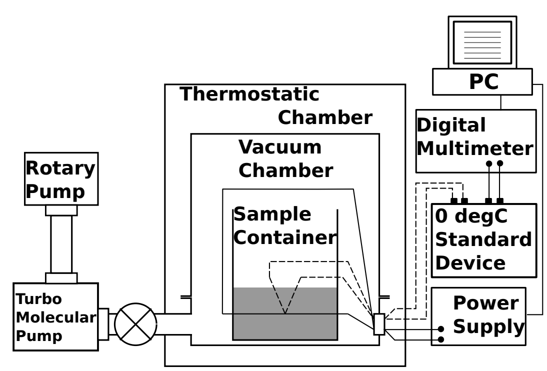

Figure 1: Experimental configuration.

Results and Discussions: Figure 2 shows measured thermal conductivity as a function of the temperature. The thermal conductivity of all samples increased with the temperature. Assuming that the temperature dependence is caused only by the radiative contribution, the equation $k_{eff} = A + BT^3$ was fitted to the experimental data (Figure 2), and the values of A and B were determined for each size of glass beads (Figure 3). The solid conductivities in our results were in 0.001 to 0.003 W/mK. These were much higher than the results of Watson and Merrill, and slightly increased with the particle size. On the other hand, the radiative conductivity increased with the particle size and it is consistent with the results of them. The larger particles form the broader void space, which makes the radiative conductivity higher according to the parallel slabs' model [4].

Wechsler *et al.* [3] explained the decreasing feature of the solid conductivity with increasing particle size, in terms of the number of interparticle contacts per unit volume. However, thier explanation did not include the dependence of the conductance per one contact on the particle size. This effect is difficult to examine analytically, because the contact conductance is dependent on many unkown factors, such as microtexture of the particle surface, paking configuration, etc. In the specific case, as cubic array of the uniform spheres, the solid conductivity is independent of the particle size [8]. With appropriate parameters, this theoretical expression derives the solid conductivity of 0.0014 W/mK, consistent with our experimental results, which indicates that the interpretation combining the number of contact per unit volume with the thermal conductance across the contact is required.

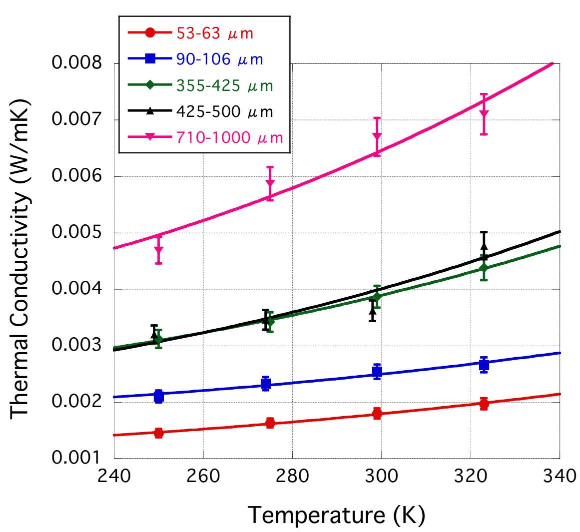

Figure 2: Thermal conductivity of glass beads as a function of temperature with vertical error bars of 10%. Five curves represents fitting results of the equation $k_{eff} = A + BT^3$.

References: [1] A. Hagermann (2005), *Phil. Trans. R. Soc. A*, 363, 2777-2791. [2] G. Akridge *et al.* (1998), *Icarus*, 132, 185-195. [3] A. E. Wechsler *et al.* (1972), In *Thermal Characteristics of the Moon*, Progr. Astronaut. Aeronaut., 28. [4] K. Watson (1964), *Ph.D. dissertation*, Calif. Inst. Technol., Pasadena. [5] R. B. Merrill (1969), *NASA Tech. Note*, D-5063. [6] J. A. Fountain and E. A. West (1970), *JGR*, 75 (20), 4063-4069. [7] H. S. Carslaw and J. C. Jeager (1959), In *Conduction of Heat in Solids*, Clarendon Press, Oxford. [8] J. D. Halajian and J. Reichman (1969), *Icarus*, 10, 179-196.

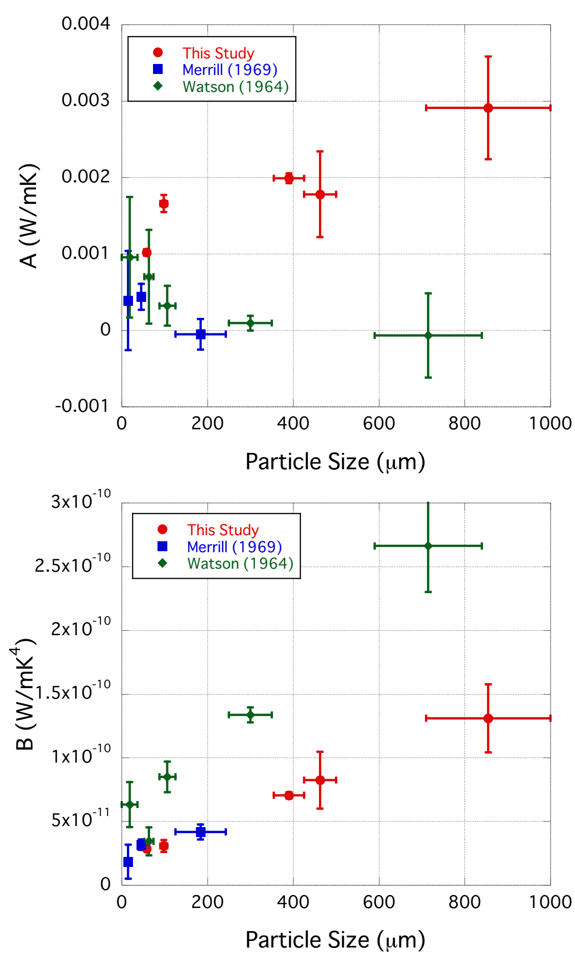

Figure 3: Solid conductivity A and radiative conductivity coefficient B as a function of the particle size (red points). For comparison, the results of Watson (1964) and Merrill (1969) are included [4, 5].