Weight reduction of TPS and insulation material by using thermal conductivity in vacuum condition

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A spacecraft contains various insulations or TPS (thermal protection system) materials to maintain its thermal condition as well as protect fuselage from external environment. Sometimes they occupy a high level of weight. Since weight is directly related to cost and performance of the spacecraft, it needs to be optimized. Thermal conductivity is a key property to decide thickness and weight of the insulation and is changes with vacuum levels. This paper introduces a measurement method and apparatus for thermal conductivity in vacuum condition and shows how it changes with measuring a TPS material.

The measurement apparatus uses a guarded hot plate [1] method and was firstly introduced by Kim et al. [2]. The measuring part is composed of a heater, guard, bottom plate and upper plate and it is installed in a vacuum chamber. The vacuum level can be controlled from atmospheric pressure to 0.1 Pa.

Thermal conductivity of a TPS material with 20mm thickness is measured using the apparatus in different vacuum condition. To verify its accuracy, thermal conductivity in atmospheric pressure is measured and compared using commercial measurement apparatus.

Table 1 Measurement result

Pressure [Pa]	Thermal conductivity [mW/m-K]		
	In-house apparatus	Commercial GHP	Commercial HFM
101325	79.2	79.3	79.6
50929	68.8	*Not measured*	
11865	64.09		
1029.25	52.69		
6.0795	43.16		
0.1149	43.15		

Table 1 shows measured thermal conductivity. In the atmospheric pressure, measured value shows very close to those of commercial equipment within 1% of relative error. It is decreased as vacuum level lowers and reached to 43 mW/m-K at 6 Pa and not decreased any further until 0.1 Pa. The minimum value is sum of solid conductivity and radiative conductivity. The difference between maximum at atmospheric pressure and minimum is around 36 mW/m-K and it is gas conductivity of contained gas in the specimen. From the gas conductivity, it is assumed that the gas is Methane which has very close thermal conductivity 34 mW/m-K at 25℃.

As shown in the result, thermal conductivity can be significantly decreased according to vacuum pressure. Therefore, if vacuum condition and corresponding thermal conductivity are considered when designing the insulation or TPS of spacecrafts, thickness and weight will be lessened. It means the performance enhancement and cost saving of whole system.

References

[1] ASTM C177-19, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

[2] Jongmin Kim et al., Measurement of Total Hemispherical Emissivity Using Vacuum Guarded Hot Plate, Journal of Heat Transfer, ASME, 134, 2012