APOLLO 12 THERMAL RADIATION PROPERTIES*

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Abstract. The spectral and total thermal radiation properties as a function of bulk density are presented for lunar fines from the Apollo 12 mission. The total emittance is presented as a function of temperature from 90 to 400°K and the solar reflectance (albedo) for near normal incidence.

1. Introduction

The most realistic calculations of the diurnal temperature variation of the lunar surface use variable thermophysical properties, Cremers *et al.* (1971, a, b, c). The proper design of scientific equipment and structures on the lunar surface also require the thermophysical properties of the lunar surface material. In this paper we present the spectral thermal radiation properties of lunar surface material, the total emittance and solar reflectance (albedo) as a function of material bulk density.

The lunar fines investigated in this study were collected by the Apollo 12 mission on the Ocean of Storms and are from the contingency sample. It was found that the landing site is covered to a depth of several meters or more by a layer of finely divided soil or fines. The bulk densities of the fines used in this study bracket those observed in the returned core-tube samples. The lower bulk densities are felt to be more nearly that which one would find on the lunar surface.

2. Measurement Techniques

The total near normal emittance as a function of surface temperature was calculated using

$$\varepsilon(\theta, T) = \frac{\int_0^\infty \varepsilon(\lambda, \theta, T)\, i_B(\lambda, T)\, \mathrm{d}\lambda}{\int_0^\infty i_B(\lambda, T)\, \mathrm{d}\lambda}, \tag{1}$$

where $\varepsilon(\lambda, \theta, T)$ is the directional spectral emittance, θ the angle of viewing, T the temperature of the sample and $i_B(\lambda, T)$ is the Planckian intensity distribution of black body radiation. $\varepsilon(\lambda, \theta, T)$ was determined experimentally using the following technique (Birkebak, 1971).

Figure 1 presents a schematic of the spectral emittance system. The technique is to provide the sample with a well defined surrounds. Radiation collected by the transfer

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optics is focussed on the slit of a spectrometer. The radiation from the sample includes both emitted energy from the sample and energy from the surrounds reflected by the sample in to the direction of viewing. The transfer optics are adjusted so that energy from a reference black body and the surrounds can be measured. The three sets of energy measurements along with the temperature of the sample, reference black body, and surrounds, respectively, allows one to calculate the directional spectral emittance. A complete description is presented by Birkebak (1971).

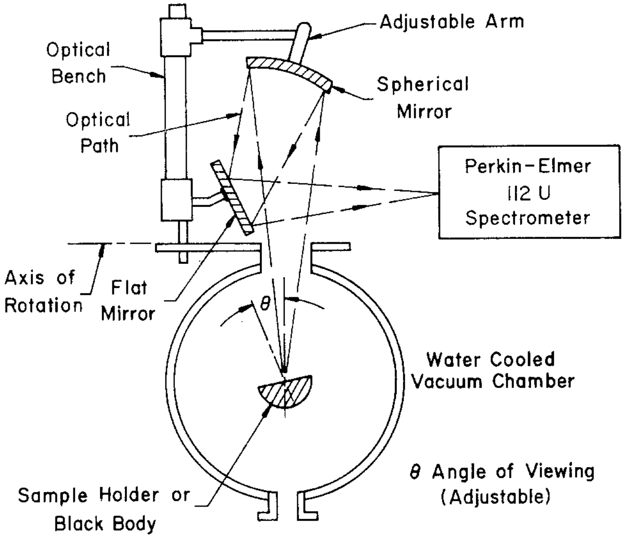

Fig. 1. Schematic of emittance apparatus.

The solar reflectance was calculated using spectral directional reflectance results for lunar fines (Birkebak *et al.*, 1971) and the solar distribution of Johnson (1954). The center-mounted sample integrating sphere reflectometer technique employed to obtain the spectral directional reflectance is described in detail in Birkebak *et al.* (1970). The directional reflectance used in this paper refers to the condition that the surface is illuminated by incident radiation contained in a small solid angle oriented at a specific angle relative to the surface normal. The energy reflected is collected over the hemispherical space above the surface.

3. Sample Preparation

The sample holders were either a Teflon cup 25 mm in diameter and approximately 3 mm in depth for the reflectance measurements or a aluminum dish of approximately the same size as the Teflon cup, highly polished, with one thermocouple in the base of the dish and a second bare thermocouple stretch across the top of the holder for surface temperature measurements in the emittance method. Samples were measured out to the proper weight corresponding to the desired density and then carefully poured into the sample holder. To achieve a level surface the fines were packed by use of a vibrating tool held on the holder edge. Initial packing and smoothing of the surface is achieved with a stainless steel spatula.

4. Results

The spectral emittance of sample 12070 as a function of bulk density for an angle of viewing of 10° is shown in Figure 2. Each curve represents an average of 3 or more runs and were drawn through data points taken every 0.25 μm. The band width for these measurements varied from 0.5 μm at 2.5 μm to 0.36 μm at 14.75 μm. The estimated error in these measurements is ±1%.

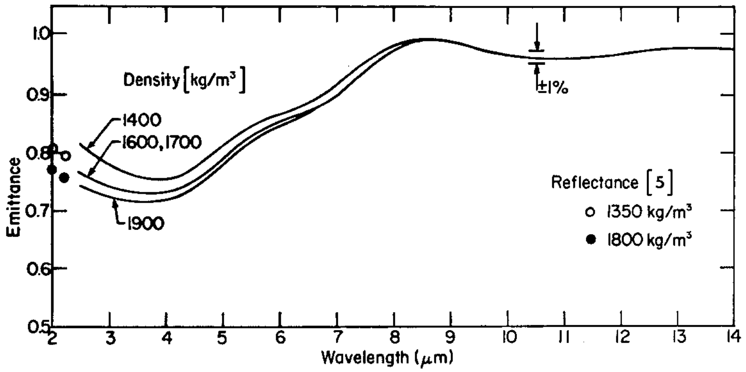

Fig. 2. Spectral emittance of Apollo sample 12070.

The spectral emittance has a minimum of 0.71 at approximately 3.75 μm for a density of 1910 kg/m^3 and a maximum of 0.995 at approximately 8.5 μm. Because our band width was large and the maximum emittance region broad, it is difficult to establish where the emittance reaches its maximum value. The maximum emittance occurs near the frequency where the index of refraction of the surrounding medium and fines are equal and at the Christiansen frequency of minimum internal scattering in the fines. Also there is an apparent absorption band centered at approximately 5.5 μm.

The effects of bulk density are clearly evident in the results and the maximum effects occur at the shorter wavelengths. The emittance decrease with increasing density and changes approximately 10% at 3 μm between the smallest and largest densities used. This decrease can be explained by the fact that as the density increases, the void fraction decreases, and hence the number and size of the voids decrease, which emit and absorb energy as small cavities. From our results we believe that we have reached the maximum effect of density and further increase of density would not have any effect, that is, the material behaves as if it were a solid. This conclusion was also reached by Birkebak *et al.* (1971) for density effects on reflectance. For longer wavelengths the difference between the results of all bulk densities were negligible.

The total emittance as a function of density and temperature is shown in Figure 3. The lunar surface is not black, an emittance of one, as some investigators have assumed in their analyses of lunar temperature variation, but the emittance varies from approximately 0.972 to 0.927 for a temperature range from 90 K to 400 K, the expected temperature range on the lunar surface.

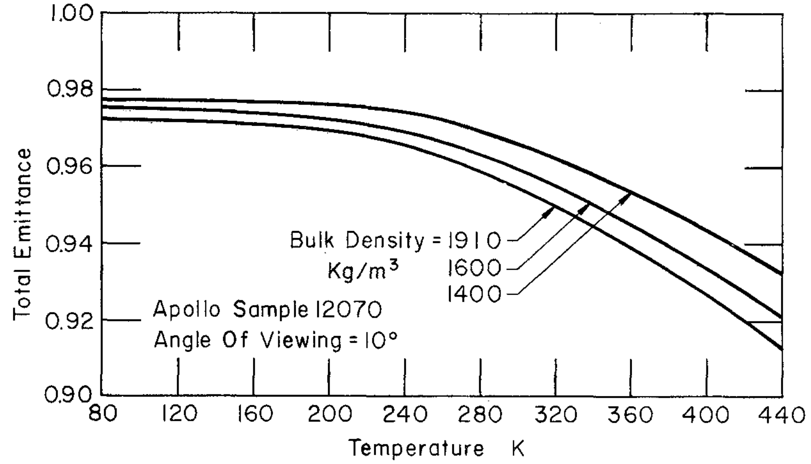

Fig. 3. Total emittance as a function of temperature-Apollo 12070.

The equation representing the emittance as a function of temperature for a bulk density of 1910 kg/m^3 is

$$\varepsilon = 0.9843 - 0.2037 \times 10^{-3}\ T + 0.1863 \times 10^{-5} T^{-2} - 0.6765 \times$$
$$+ 10^{-8} T^{-3} + 0.6436 \times 10^{-11} T^{-4}$$

where T is the absolute temperature in degrees Kelvin.

The spectral reflectance of Apollo sample 12070 as a function of density is shown in Figure 4. These results have been discussed previously by Birkebak *et al.* (1971). In general the reflectance increases with density for all wavelengths with an increase of up to 40% from the smallest to largest densities. Comparison of the reflectance and emittance results at wavelengths near 2 μm, Figure 2, are good for the higher densities, that is, there is a reasonable match of the measured values of emittance and one minus the reflectance, but poor agreement for the density of 1400 kg/m^3.

The solar reflectance (albedo) which is needed in the analysis of lunar heat transfer is presented in Table I. The albedo varies by 20% for densities from 1300 to 1800 kg/m^3. The equation fitted to the albedo as a function of angle of illumination for a density of 1800 kg/m^3 is

$$\varrho(\theta) = 0.120 - 0.0284\theta + 0.193\theta^2 - 0.1324\theta^3 - 0.23725\theta^4 + 0.251593\theta^5$$

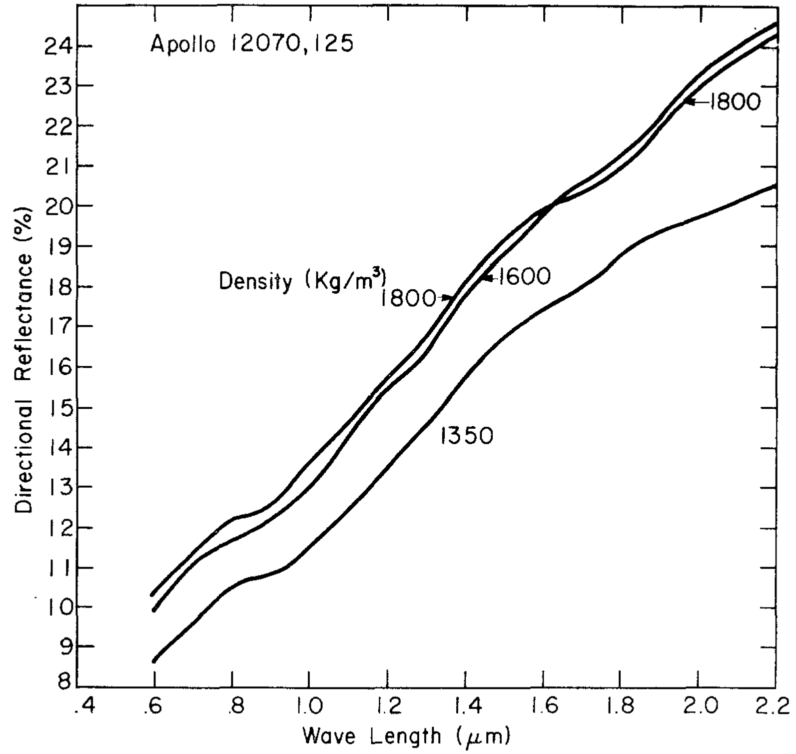

Fig. 4. Spectral directional reflectance as a function of bulk density-Apollo 12070, angle of illumination 10°.

TABLE I

Solar albedo of Appollo 12 fines 12070

Density kg/m^3

Angle of illumination	1300	1600	1800
10	0.101	0.119	0.120
20	0.106	0.114	0.126
30	0.109	0.115	0.131
45	0.122	0.136	0.138

where θ is the angle of illumination in degrees. This equation satisfies the condition that as θ goes to 90°, $\varrho(\theta)$ goes to one, a necessary condition to satisfy reality.

These variable thermal radiation characteristics have been used by Cremers *et al.* (1971a, b, c) to calculate the lunar surface temperature and the variation of temperature of depth as a function of lunar times. The variation of emittance with temperature and albedo with angle of illumination greatly effects the temperature just after sunrise and before sunset when compared to the constant property solutions.

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