

An innovative method for emissivity calibration at the Planetary Emissivity Laboratory (PEL)

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Abstract

The Planetary Emissivity Laboratory (PEL) at DLR in Berlin is equipped with two FT-IR spectrometers to allow measurements from the visible to TIR range using bi-conical and bi-directional reflection, transmission and emission spectroscopy.

The facility core is the emissivity spectrometer laboratory, with a supporting spectrometer laboratory for reflectance and transmission measurements, sample preparation equipment, and an extensive collection of rocks and minerals.

In this paper we illustrate a new developed technique for the calibration of emissivity measurements. This new approach allows determining the absolute emissivity of the measured materials, while eliminating the need for simplifications based on a-priori assumptions on which previous methods relied.

1. The PEL Set-up

The high temperature emissivity chamber is connected to a Bruker VERTEX 80V and can be evacuated to ~ 0.1 mbar. An induction heating system heats the samples to temperatures of up to 700K, while the surroundings remain cold. A computer-controlled carousel allows measuring up to 11 samples without breaking the vacuum. The second purged emissivity chamber is connected to an older Bruker IFS 88 spectrometer. A heater in the chamber heats the sample cups from the bottom, from 20° up to 180° C. The cooling system build in the walls of the chamber allows to set the chamber temperature to typically 10° or 20° C, or even below zero (see [1,2] for details).

With the Bruker A513 accessory on Vertex 80V, we get bi-directional reflectance of minerals, with variable incidence and emission angles between 13° and 85°. We measure at room temperature, under purge or vacuum conditions, covering the 1 to 100 μm spectral range.

A Harrick Seagull™ variable angle reflection accessory on the Bruker IFS 88 allows measuring bi-directional reflectance of minerals, under purging conditions in the extended spectral range from 0.4 to 55 μm for angles between 5° and 85°.

2. Emissivity determination

Emissivity (or emission, or emittance) is a quantity not directly measurable in a laboratory. By definition, it is the ratio of the radiance emitted from a body at a certain temperature, divided by the radiance emitted from a blackbody at exactly the same temperature. Unfortunately this seemingly simple formulation poses some serious experimental challenges. To calculate the emissivity following its theoretical formulation, some crucial achievements are needed: a precise measurement of the sample temperature (or better, of its emitting skin layer), an experimental geometry where the optical path-length between detector and sample and detector and blackbody, is exactly identical, a very good experimental knowledge of the blackbody emissivity curve, and its behavior/invariability at different temperature ranges as well as its stability at high temperatures (700 K typical daily on Mercury).

Since the publication of the pioneering work of [3], all the experimenter followed the method described in that paper to calibrate emissivity. It is based on the assumption that emissivity equals 1 in a point of the spectrum (Christiansen feature, or CF), consequently the sample reflection, here again approximate as $r=1-e$, equals zero and the formula for emissivity is easily solved [1].

Even if for most of the silicate minerals the CF reaches almost unity, it is true that for rocks or mixture, composed of several phases having different CF positions, the problem is unfortunately not that easy. Especially in vacuum, and always when no equilibrium exist between the emitting layer and its surroundings, the approximation $r=1-e$ is not valid

and potentially leads to significant misinterpretation of the data.

The calibration method we introduce in this paper is a mixture between a rigorous physics formulation, an optimized instrumental set-up, and some technical advancement. We propose to follow the theoretical formulation directly to calculate the emissivity of a material. We devoted almost a year to overcome the experimental challenges associated with this approach. This included testing a large variety of temperature sensors and measurement configurations. We measure a cup containing the heated sample, with a temperature sensor embedded in the sample surface, reading the temperature of the emitting skin (see Figure 1).



Figure 1: One temperature sensor tested at PEL.

The sensor has no contact with the cup rim or any other hot source. To decrease thermal gradients in the sample emitting layer, we developed cylindrical rims of stainless steel for our cups, with the advantage that the rim itself will be hot and will therefore equilibrate the cooling of the sample surface. Placing the sample and the calibration blackbody on the sample carousel, it permits to measure the two sources with exactly the same observation geometry, allowing the determination of an absolute value of sample emissivity. As calibration blackbody, we use a blast furnace slag, because it has a very high emissivity, almost independent from temperature within the temperature range considered here and exhibiting no change due to thermal cycling. To derive the sample emissivity, we measure the sample at a certain temperature T , and then we divide this radiance (I) for the blackbody radiance (BB) measured at the same temperature T . In order to obtain the same temperatures we use a closed-loop temperature control for the induction system. Taking into account

that the absolute emissivity of the blast furnace slag used as blackbody is known, the ratio can be corrected for this value yielding the absolute emissivity. In Figure 2 we show the difference we found between calculating the emissivity following the method exposed in [3] (E) and the one from the present paper (I/BB) for a rock sample in the $0-25\mu\text{m}$ grain size. The emissivity measurements were taken in purged air, at low temperature (50°C). In this conditions, the approximation $R=1-E$ is valid, so we can compare the measured emissivity with $1-R$, where R is the reflectance of the same sample. Figure 2 shows how good the $1-R$ and the I/BB measurements agreed especially in comparison to the emissivity calculated following the old method by [3].

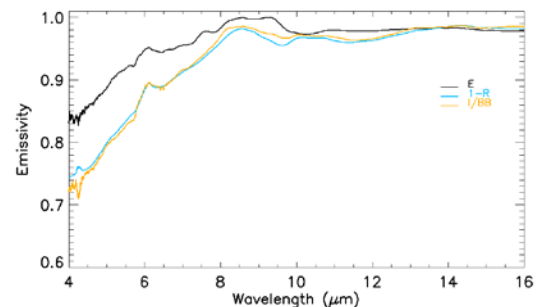


Figure 2: Emissivity calculated following our new approach (I/BB), the old method by [3] (E) in comparison with emissivity derived from reflectance ($1-R$).

3. Summary and Conclusions

At PEL we can measure emissivity and reflectance under several conditions. We developed a set-up to measure, and a method to calibrate the emissivity spectra of a sample that avoids most of all imprecisions arising from approximations and a-priori assumptions in previously used methods.

References

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