EFFECTS OF VARYING TEMPERATURE AND PRESSURE CONDITIONS ON EMISSIVITY SPECTRA: APPLICATION TO THERMAL INFRARED OBSERVATIONS OF AIRLESS BODIES.


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Introduction: A fundamentally important component to any remote sensing study of planetary surfaces is laboratory measurements of well-characterized samples measured under the appropriate environmental conditions. In the vacuum, near-surface environment of airless bodies like the Moon and asteroids, there are no interstitial gases between regolith grains to transfer heat via conduction. Thus, radiative cooling dominates and a thermal gradient in the upper hundred microns of regolith is created. Lab studies of particulate rocks and minerals as well as selected lunar soils under vacuum and lunar-like conditions have identified significant effects of this thermal gradient on thermal infrared (TIR) spectral measurements [e.g. 1-5]. Compared to ambient conditions, these effects include: (1) the Christiansen feature (CF), an emissivity maximum diagnostic of composition [6], shifts to higher wavenumbers and (2) an increase in spectral contrast of the CF relative to the Reststrahlen bands (RB), the fundamental molecular vibration bands due to Si-O stretching and bending. Such lab studies demonstrate the high sensitivity of TIR emissivity spectra to environmental conditions under which they are measured.

Experimental Setup: The Asteroid and Lunar Environment Chamber (ALEC) is in the initial stages of calibration and integration as the newest addition to Brown University’s Reflectance Experiment Laboratory (RELAB) [7]. The vacuum chamber is designed to simulate the space environment experienced by the near-surface regolith of the Moon and asteroids. The internal rotation stage allows for six samples and two blackbodies to be measured without breaking vacuum (<10^-3 mbar). Liquid nitrogen cooling lines are used to cool the interior of the chamber, thus creating a cold, low emission environment for heated samples to radiate into. Samples can be heated in one of three ways: (1) from below using heaters embedded in the base of the sample cup, (2) from above using a 25 watt halogen lamp heat source with a fused silica window to remove long wavelength IR, and (3) from below and above. ALEC is connected to RELAB’s Thermo Nicolet 870 Nexus FTIR spectrometer which allows laboratory emissivity spectra to be collected at a resolution of 4 cm^-1 over the ~400 – 2000 cm^-1 spectral range. For experiments with low atmospheric pressure (e.g. Mars), the chamber can also be backfilled to any pressure using a dry air generator that is also used to purge the FTIR.

Figure 1. Fine particulate (< 25 μm) anorthite measured under varying (top) internal chamber pressure, (middle) solar lamp power, and (bottom) sample cup heater temperature. Note that each plot is on the same y-scale to illustrate the scale of the spectral effects resulting from changing each parameter.
An initial set of experiments have been run to best understand how variations in three variables affect spectral measurements of fine particulate (<25 μm) mineral separates as well as bulk lunar soils: (1) the internal chamber atmospheric pressure, (2) amount of heating (power) from the solar-like halogen lamp, and (3) sample cup temperature (heating from below). The internal pressure of the environment chamber is varied between 1000 and <10⁻³ mbar as samples are heated from below and held at a constant temperature of 405K and no heating from above by the halogen lamp. Next, the power of the halogen lamp is varied between 0 and 25 watts while the internal pressure (<10⁻³ mbar) and heating from below (405K) are held constant. Finally, the temperature of the heater embedded in the bottom of the sample cup is varied between 300 and 405 K while the internal pressure (<10⁻³ mbar) and power of the halogen lamp (18 watts) are held constant. For all of these initial measurements, the interior of the environment chamber was not cooled as LN2 cooling was not yet available.

Results: To best constrain the regolith properties on the lunar surface, initial measurements were made of a fine particulate (< 25 μm) anorthite sample. By varying only the internal chamber pressure, a thermal gradient is formed in the upper hundreds of microns in the fine particulate anorthite sample which causes the following spectral differences: (1) the spectral contrast of the CF relative to the RB is enhanced and (2) the CF shifts to higher wavenumbers (top plot in Fig. 1). Spectral differences seen between anorthite measured under 1000 mbar of pressure versus 5 mbar suggests that Mars-like atmospheric pressure conditions creates a small thermal gradient in fine particulate materials. As the power of the solar lamp increases, thus increasing the heat at the surface of the sample, the spectral contrast of the CF relative to the RB decreases and the CF shifts to lower wavenumbers (middle plot in Fig. 1). Changes in the pressure and halogen lamp power lead to competing spectral effects on the same scale. Whereas varying the temperature that the sample is heated to from below does not change the anorthite spectra (bottom plot in Fig. 1).

To truly capture thermal gradient effects on the properties of the lunar regolith, bulk lunar soil samples need to be measured under varying conditions in the same way that the fine particulate anorthite sample was measured. Initial measurements of bulk lunar soils from the Apollo 11, 15, and 17 landing sites are seen in Fig. 2. These lunar soils were measured under vacuum pressure (<10⁻³ mbar), heated from below to 405K and the power of the solar lamp was 18 watts. Note the y-scale differences between Figures 1 and 2. The spectral contrast of the CF and RB in actual bulk lunar soil spectra is not as great as the CF and RB in the spectra of the fine particulate anorthite sample measured under the same conditions.

Discussion: These early results corroborate previous lab measurements showing the sensitivity of TIR spectra to the conditions under which they are measured and for the first time illustrates how the pressure and the way in which a sample is heated each contribute to the changes in TIR spectral measurements. While the samples are not yet measured in a LN2 cooled environment, RELAB will be moving to a new facility in January where LN2 is available and all of the samples will be re-measured to understand any additional effects of a cooled environment.

To accurately simulate the near-surface environment of the Moon in ALEC, spectral measurements of lunar soils under varying controlled conditions will be compared with Diviner data of the Apollo landing sites. Once laboratory temperature and pressure conditions are well understood, spectral measurements will focus on building a spectral library of well-characterized minerals, rocks, soils, and meteorites measured under lunar environmental conditions. Such measurements are essential to interpret current TIR datasets like Diviner and future missions like OSIRIS-REx.

References: