

An instrument to measure spectral emittance from 2 to 20 micrometers

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Abstract

The measurement of the infrared energy emitted from materials has been of interest since at least the time of Coblenz. Applications for Space, Solar Energy, etc. have increased the interest in the field in the last twenty-five years. The emittance of a sample at any given wavelength is one minus the sum of the reflectance and transmittance. ($E=1.-(R+T)$). The instrument described here illuminates the sample at near normal incidence and collects all of the reflected or transmitted flux with an integrating sphere. Since the flux on the detector in this case is orders of magnitude less than if it could be focused, it is necessary to use a Fourier Transform spectrophotometer to get adequate signal to noise. To obtain good photometric accuracy, a true double beam system is used which simultaneously observes the sample and a reference. This eliminates the effects of drift in the source, detector, interferometer, etc. This system also has an advantage over hohlraum and ellipsoidal reflector systems in that very little energy irradiates the sample and therefore no heating occurs. This system uses an IBM-PC for the data processing. The transmittance of lenses and irregular samples can also be measured. Representative sample spectra are shown for a variety of applications.

Introduction

Emittance at a given wavelength is defined here as the ratio of the radiant flux emitted from a sample at a given temperature to the flux emitted from an ideal black body at the same temperature. Knowledge of emittance is important in all problems involving radiative heating and cooling. Such problems include solar heating, insulation, protection from solar heating in spacecraft, radiant heating in industrial processes, etc. Emittance is also important to thermal infrared sensors where the flux observed from an object is a function of both its temperature and its emittance. Until the advent of new technologies in the past two decades, it was quite difficult to get measurements of this important parameter. We here describe an instrument which measures hemispheric emittance as a function of frequency (or wavelength) of a broad variety of samples in the 2 to 20 micrometer spectral region.

The geometry of the measurements

An earlier version of the instrument was described in detail in a previous paper¹. We will briefly review here some of the more salient features of the measurements. If the sample is opaque, the emittance at a given frequency (or wavelength) is equal to the absorptance or one minus the reflectance ($E=1.-R$). If the sample is transparent, then the relation is $E=1.-(R+T)$. The instrument in question has the ability to measure essentially all of the energy reflected and transmitted in the 2 to 20 micrometer spectral region. Figure 1 shows the geometry of the reflectance measurement. A horizontal sample is measured at near normal incidence. (This also allows the measurement of liquids and powders.) All of the reflected flux is gathered by an integrating sphere. The sphere is highly reflective and diffusely reflecting in the spectral region of interest. This makes the signal on the detector a function of the amount of reflectance of the sample but not the direction of the reflected light such as specular or diffuse reflectance. The measurement is referred to as "directional-hemispheric" (D-H) since the sample is directionally illuminated and the reflected flux is hemispherically collected.

When the sample is transparent, the total transmittance is measured as follows. Two identical high reflectors are placed in the reference and sample reflectance ports so that a 100% transmittance line can be recorded. The sample is then placed over the entrance port for the sample beam and its transmittance spectrum is recorded. All of the flux transmitted in the forward hemispheric direction is collected by the integrating sphere. The transmittance and reflectance spectra can then be added together frequency by frequency by the instrument's computer and subtracted from one (1) to give the emittance at each frequency. The emittance curve can then be multiplied by the black-body curve at the measurement temperature and integrated to give the emissivity of the sample at that temperature. To the extent that the emittance does not change with

temperature, the spectral emittance curve could be multiplied by the blackbody curve at any temperature and integrated to give the emissivity at any temperature of interest. This is a reasonable assumption for some classes of samples and ranges of temperatures. This clearly would not be true if the assumed temperature were above the boiling or burning point of the sample in question. It is possible to measure samples at other than ambient temperature to the extent that the sample heating or cooling does not significantly deteriorate the functions of the instrument by melting or frosting the components, etc. Only a few limited experiments of this type have been performed to date, but it is estimated that 80 to 400 degrees Kelvin might be practical sample temperatures with some special preparations.

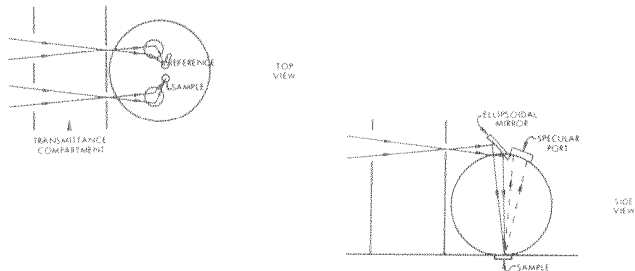


Figure 1, Integrating sphere geometry used for Directional-Hemispheric (D-H) reflectance and emittance measurements.

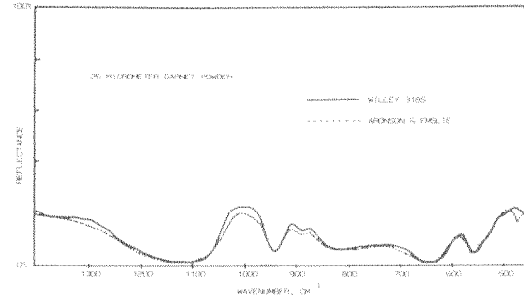


Figure 2. Reflectance of 25 micrometer particle size garnet powder obtained with WILLEY 318S and by Aronson and Emslie by observing the emitted energy of a heated sample.

The major limitation of the measurement as discussed in the previous paper¹ is the signal to noise ratio. The noise is on the order of 1/2% at the peak of the instrument's spectral response at 10 micrometers at 32 wavenumber resolution with a few minutes of data gathering time.

It is possible with some special arrangements to measure hemispheric-hemispheric (H-H) reflectance. In this case, two highly reflective, highly diffuse samples are placed in the reference and sample reflectance ports. An additional baffle is positioned so that the specular port cannot see the sample and reference beams where they fall on the normal sample positions. The sample to be measured in H-H mode is placed in the open specular port and the spectrum is recorded. In this case, all of the flux illuminating the sample has been reflected at least once from the sphere wall and is therefore in the form of hemispheric illumination. The signal registered by the detector is a function of the reflectance of the sample and the sphere wall and their relative areas. Then a sample of known high reflectance is placed over the specular port and its spectrum is recorded; the spectrum of the open specular port is recorded as the 0% H-H reference. One can then calculate the relative H-H reflectance of the sample to the reference. The change in signal from a 0% to a 100% sample is about 1/10th of the total signal and therefore the signal to noise ratio is about 1/10th what it is in the usual D-H measurement. This method is somewhat more involved than the usual D-H method and has therefore only been done on a few occasions.

The heated cavity or hohlraum methods discussed in reference 1 provide hemispheric illumination and directional observation (H-D) which is assumed to give the same results as D-H. The disadvantages of the hohlraum include limitations on sample characteristics such as size, thermal conductivity, and ability to withstand the environment due to the high thermal flux level falling on the sample. In the instrument described in this paper, the flux level on the sample is comparable to a 100 watt source at one meter distance from the sample.

We reported earlier² on the comparison of the measurement of emittance as we describe it here versus heating a sample and measuring the spectrum emitted in a given direction. Our results compared with those of Aronson and Emslie³ to within a small experimental error. Figure 2 shows that comparison.

The spectral measurement

As discussed in the previous paper¹, the integrating sphere geometry required for photometric accuracy has the disadvantage of losing two to three orders of magnitude in signal on the detector as compared to a conventional transmittance spectrophotometer. This then dictates the need to use some technique such as Fourier Transform Infrared (FTIR) spectrophotometry to recoup the loss and allow the measurements to be made in a reasonable integration time. The uniqueness of the FTIR spectrophotometer used here is

that it is a true double beam system. The spectrum of the sample and the reference are recorded simultaneously for photometric accuracy. This means that the variations in source brightness, detector response, interferometer alignment, atmospheric absorption, etc. effect both beams equally and therefore do not effect the ratio of the sample to the reference reflectance. Figure 3 shows the layout of the instrument which was described in more detail in the previous paper¹. A rotating chopper multiplexes the spectrally modulated energy between the reference and sample beams. The beams are spectrally modulated by the scanning mirror of the Michelson interferometer. The detector and processing electronics demultiplex the channels and digitize the data (interferograms). The computer converts the interferograms into spectra. The sampling of the interferograms is determined by the zero crossings of the interference of a HeNe laser which passes through the center of the same interferometer that modulates the IR spectrum. The signal to noise ratio in the resulting spectrum is proportional to the square root of data integration time. To reduce the noise in the spectrum to 1/10th, it is necessary to integrate for 100 times as long. This would be, for example, a change from the routine 5-6 minute scan time to about 8 hours.

Our current estimate of the uncertainty in the emittance measurement at 10 micrometers for a 2 hour measurement at 32 wavenumber resolution is as follows:

Reference gold mirror by "V-W" absolute calibration	.005
Effects of non-uniformity in integrating sphere	.005
Effects of non-Lambertian reflectance of sphere	.010
Effects of 0% line noise	.005
RMS noise	.001

Therefore, we estimate the uncertainty of emittance at 10 micrometers to be:

$$\Delta E = .001 + .020 (1-E)$$

This implies that for E .93 the error is .0024 and for E .5 the error is .011 when the samples are run for 2 hours each.

Example spectra

Figures 4 through 9 show various examples of materials measured with the instrument. The display is either in percent reflectance or LOG(1./Reflectance), whichever best shows the spectral content. Figure 4 shows animal materials of human hair and skin and lamb's wool. Figures 5 and 6 show vegetable materials such as cotton and papers which are mostly cellulose and two types of leaves. Figures 7 and 8 show mineral materials of sand and limestone with a comparison of seashell that has the same calcium carbonate spectrum. Figure 9 shows solar energy related surfaces, specifically "white" roof tiles as used in the trop-ics to minimize the heat gain from the sun and maximize the thermal radiative loss; whereas the black chrome plating is used to do the opposite.

Conclusions

We have described some methods and a specific instrument to measure spectral emittance of materials in the 2 to 20 micrometer region. The variety of samples that can be measured is quite broad and the ease and accuracy of the measurements is adequate for most applications. The instrument has been constructed on basic principles which allow greater refinement in the results by extra effort when required.

References

1. R. Willey, "Fourier Transform Infrared Spectrophotometer for Transmittance and Diffuse Reflectance Measurements", Applied Spectroscopy, 30, No. 5 (1976)
2. R. Willey, "Infrared reflectance: independant measurements yield good agreement", Applied Optics, 15, No. 5 (1976)
3. J. Aronson, A. Emslie, Applied Optics, 12, 2573 (1973)

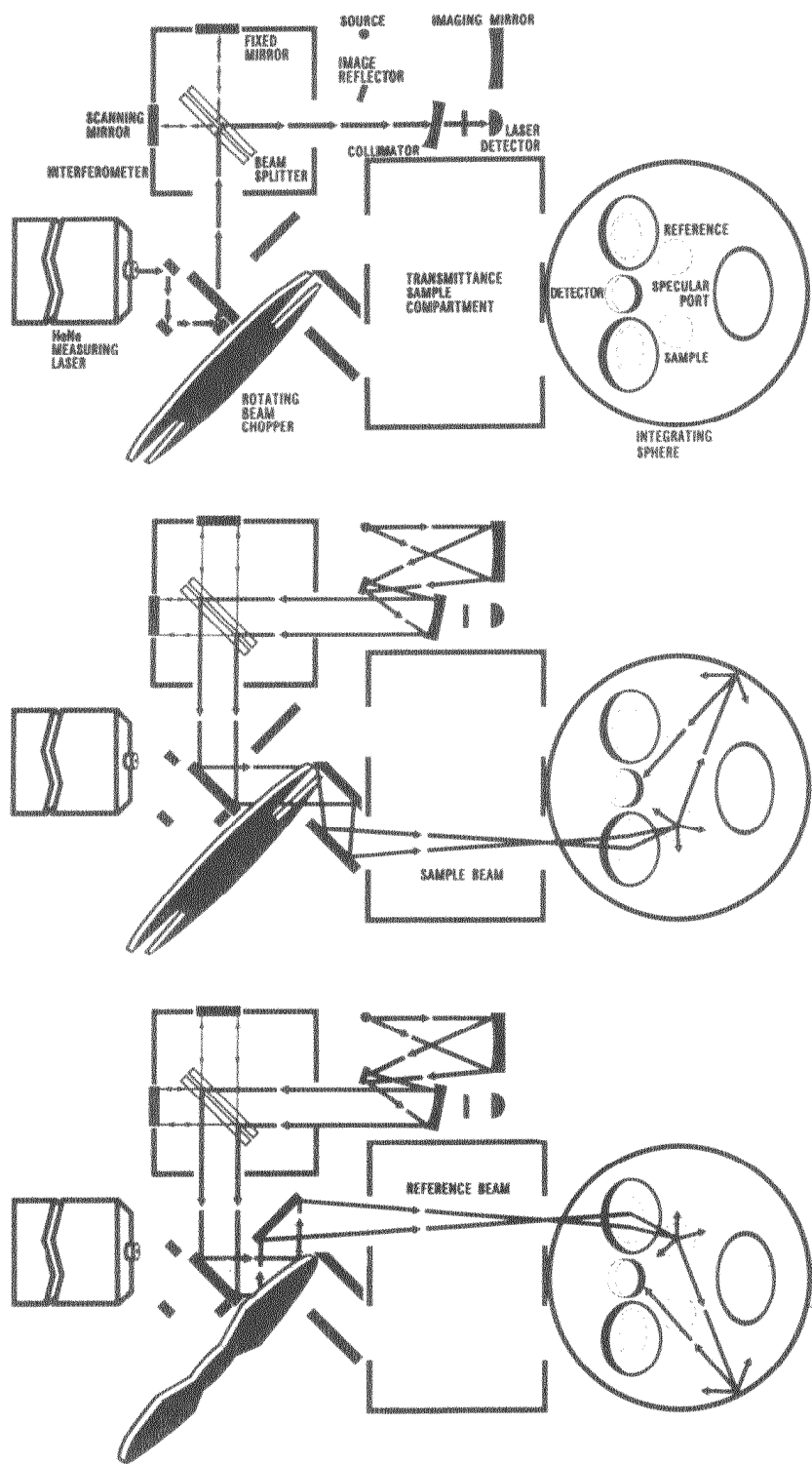


Figure 3. Optical layout of the WILLEY 318 spectrophotometer showing laser path, sample beam path, and reference beam path.

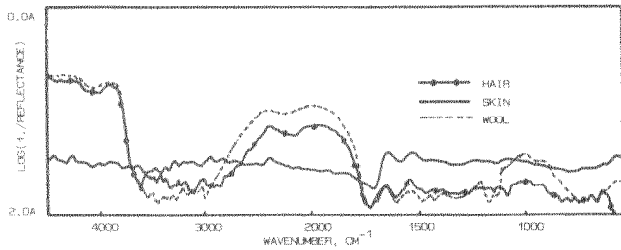


Figure 4. Reflectance of human hair, human skin, and lamb's wool.

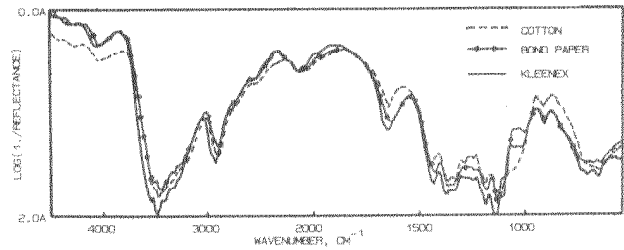


Figure 5. Reflectance of three materials that are principally cellulose: cotton, bond paper, and Kleenex tissue.

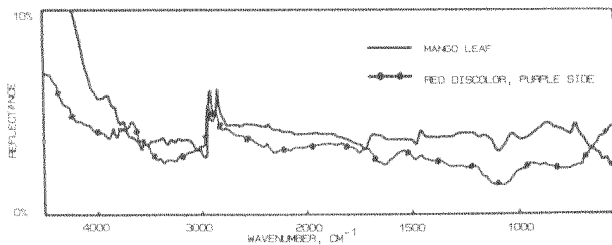


Figure 6. Reflectance of two plant leaves: mango and Red Discolor, a purple colored leaf to the eye.

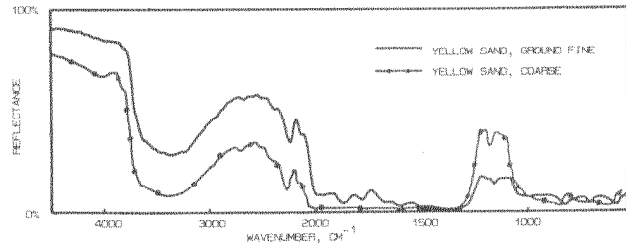


Figure 7. Reflectance of a common yellow sand from Florida in coarse form and after being ground much finer, note changes.

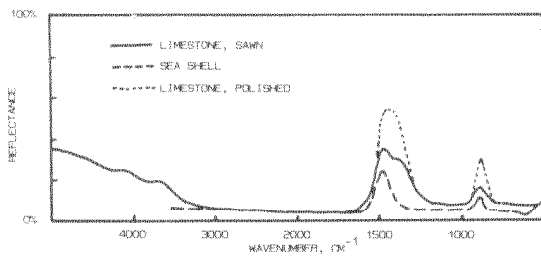


Figure 8. Reflectance of limestone sawn (course) and polished in comparison to a clamlike seashell showing calcium carbonate bands.

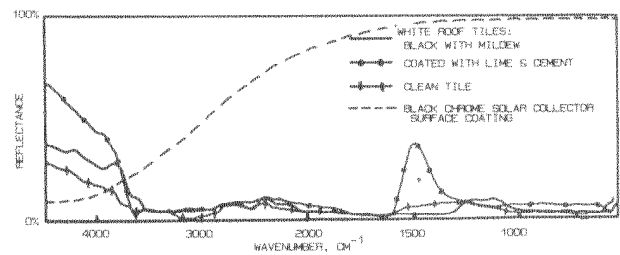


Figure 9. Reflectance of white cement roof tiles: clean, black with mildew, and coated with lime; Black Chrome for comparison.