Emittance and reflectance of various materials in the 2 to 20 micrometer spectral region

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Abstract

The infrared emittance of surfaces is of interest to various disciplines which include: thermal imaging, remote sensing, solar energy, insulation, radiative transfer in space, etc. A brief review is given of how the measurements are made. The emittance or reflectance of a variety of samples of interest to different applications are shown in the 2 to 20 micrometer (5000 to 500 wavenumber) spectral region.

Introduction

Emittance at a given wavelength or frequency is defined 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. This is 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 have previously described[1,2,3] an instrument which measures hemispheric emittance as a function of frequency (or wavelength) in the 2 to 20 micrometer spectral region. Figure 1 shows the instrument schematically. We here present example spectra of materials of interest to thermal imaging, remote sensing, etc.

The geometry 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. Diffuse Reflectance Infrared Fourier Transform (DRIFT) spectroscopy has become popular and widespread among analytical chemists since our first publication[1]. The work of analytical chemists such as Griffiths[4] et al. has advanced the qualitative applications by enhanced signal to noise. However, this has inherent limitations in photometric and quantitative analysis due to the fact that only a portion of the reflected radiation is sensed and that is with limited uniformity of response with angle[4]. The measurements reported here are therefore unique in that they cannot in general be achieved with other instruments due to either photometric limitations or the ability to handle many of these types of samples. All of the examples which we will show are opaque samples and are shown in percent reflectance in linear frequency from 5000 to 500 wavenumbers. The examples shown are rapid survey scans at a relatively low resolution of about 50 wavenumbers gathered in about five minutes each. Greater signal to noise and resolution are achievable with longer integration times.

Spectral measurement results

Figures 2 through 31 show various examples of materials measured with the instrument.

Figures 2 through 5 show the effects of increasing water content in a sample of beach sand. The strong reststrahlen band at 1150 wavenumbers is characteristic of quartz and is the last to be masked by the water. In Figure 5, the water surface was virtually level with the top of the sand. Figure 6 shows weathered concrete which indicates a strong sand content. Figure 7 shows the surface of a concrete block where the sand is not as obvious, but from our previous work[1,3] we believe shows also calcium carbonate (limestone) bands near 1400-1500 wavenumbers.

Figure 8 shows the monotonically low reflectance of common tar. Figure 9 shows a sample of "tar mack" from local road construction which appears to have a sand content, which is not surprising. A common roofing shingle is shown in Figure 10; this would have a relatively high emissivity to radiate heat to the sky. A low emittance or high reflectance is seen in the weathered aluminum sheet metal of Figure 11; aluminum foil is not dramatically different. Figure 12 shows 4 millimeters of tap water over aluminum foil; this illustrates how opaque water is over this spectral region. Thermal imagers are therefore probably only seeing the temperature effects of the first few millimeters of any body of water. By comparison, the reflectance of a frosty ice cube (surrounded by liquid nitrogen) shows the structure seen in Figure 13.

Common black anodized aluminum is seen in Figure 14. The surface is believed to be a porous form of sapphire which is seen in Figure 15 to have a decreasing reflectance to about 1000 wavenumbers and then a strong reststrahlen peak at about 750. The other bands in anodized aluminum are believed to be water and organic dyes. Note that black anodized aluminum is not necessarily a good black for the infrared. The sapphire sample of Figure 15 actually transmits most of the energy from 2000 to 5000 wavenumbers, and therefore this sample would need the R and T to compute emittance. Other examples of characteristic reststrahlen and reflectance of minerals are shown in Figure 16 and 19. Sheet mica (believed to be muscovite) is seen in Figure 16, quartz rock in Figure 17, a sample thought to be feldspar in Figure 18, and diatomaceous earth used in swimming pool filters in Figure 19.

On the vegetable side, we see typical 2x4 or 2x8 wood in Figure 20 and a surprising similarity to the bark from a Florida live oak tree in Figure 21. The reflectance of typical Florida "Saint Augustine" grass, dark "loam" soil, and grapefruit leaves all look similar in Figures 22, 23 and 24. A visually black "soot" mold on the grapefruit leaves is seen to actually have higher reflectance than the leaf in the infrared in Figure 25. The skin of a ripe orange is fairly dark in Figure 26, but a ripe grapefruit is seen in Figure 27 to be even darker than either the orange or the leaves. Again, the mold on the grapefruit in Figure 28 reflects notably more than the clean grapefruit.

On the animal side, the skin on the back of the author's hand in Figure 29 is quite dark even in the absence of significant suntan. Silicon carbide "sand" papers such as shown in Figure 30 are reasonable good diffuse blacks, but we can see some reststrahlen in the vicinity of 10.6 micrometers. White teflon has the interesting reflection shown in Figure 31.

Conclusions

We have shown the infrared reflectance (thereby emittance) of a variety of samples which represent typical surfaces which might be viewed by thermal imagers or remote sensors. Some of the spectra shown cannot have their infrared reflectance/emittance easily characterized by any other instrument at the present time. It can be seen that not all objects are black bodies in the infrared and some valuable discriminations may be possible as the technology advances.

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. R. Willey, "An Instrument to Measure Spectral Emittance from 2 to 20 Micrometers" SPIE Proceedings 590-36 (1985)

4. P.J. Brimmer, P.R. Griffiths, and N.J. Harrick, "Angular Dependence of Diffuse Reflectance Infrared Spectra", Applied Spectroscopy, 40, No. 2 (1986)

FIGURE 1. Optical layout of the WILLEY 318P Spectrophotometer showing laser path, sample beam path and reference beam path.

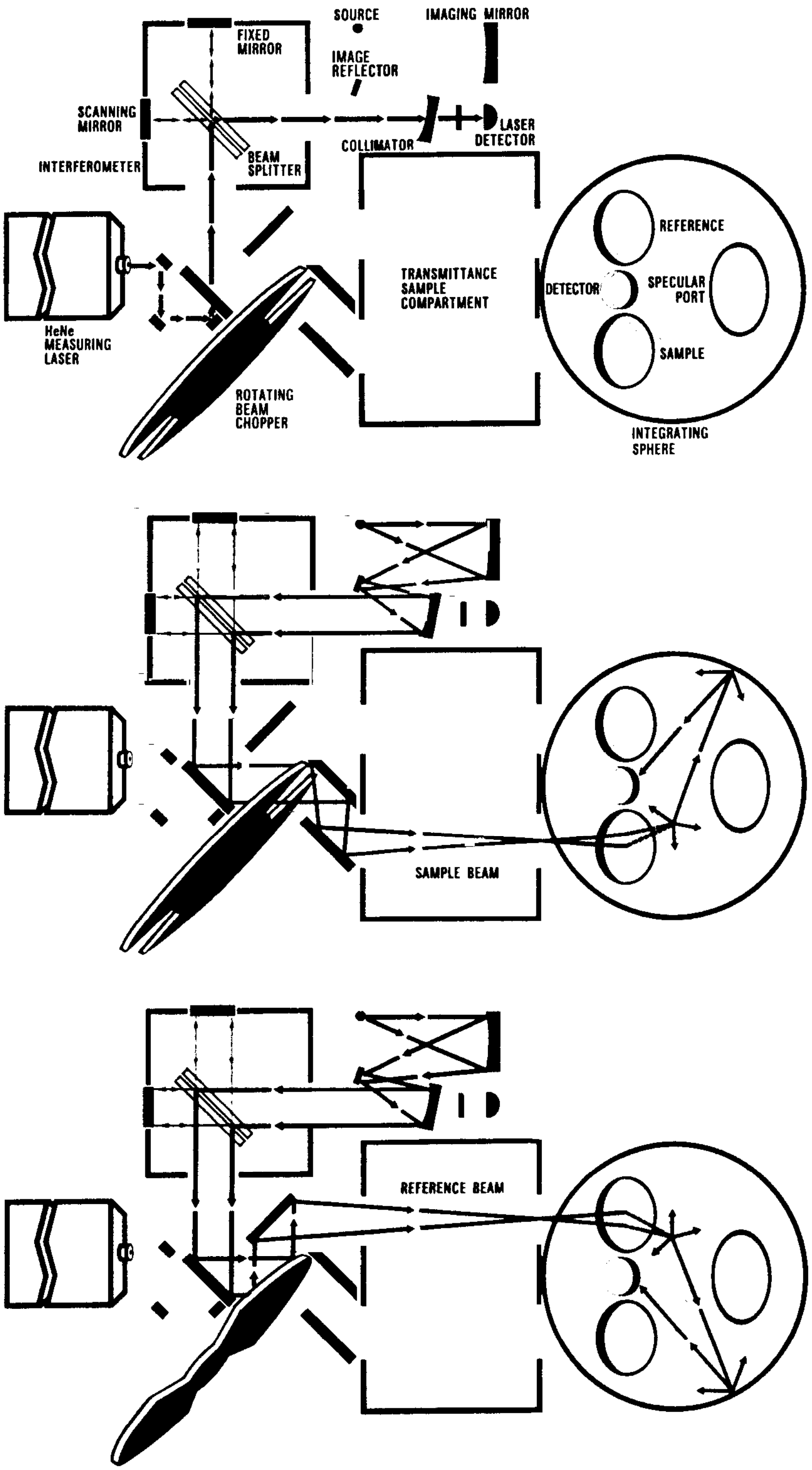

FIGURE 2

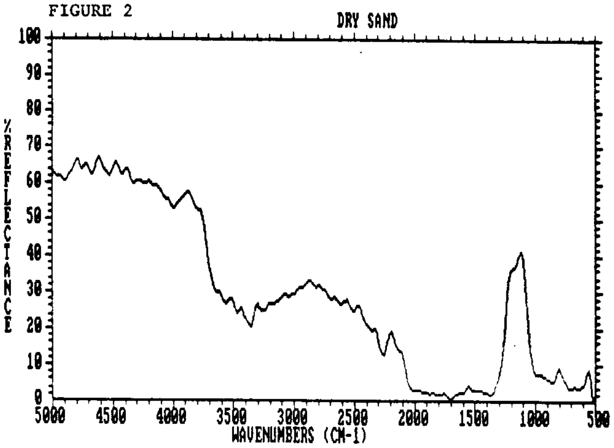

FIGURE 3

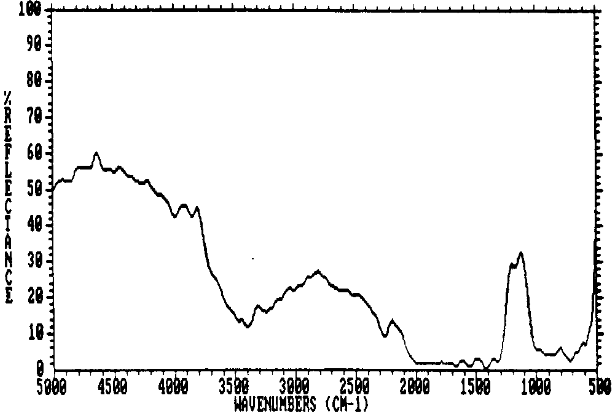

FIGURE 4

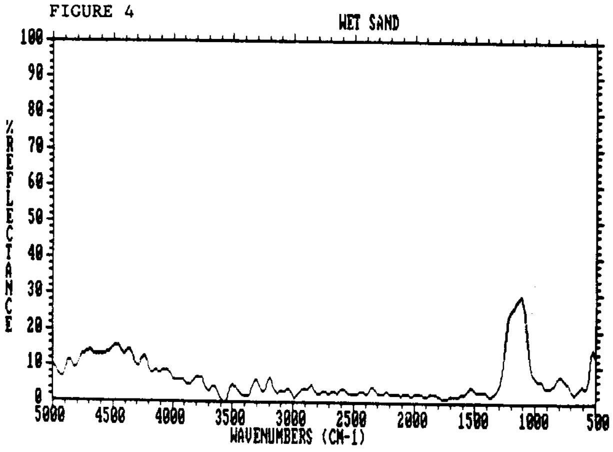

FIGURE 5

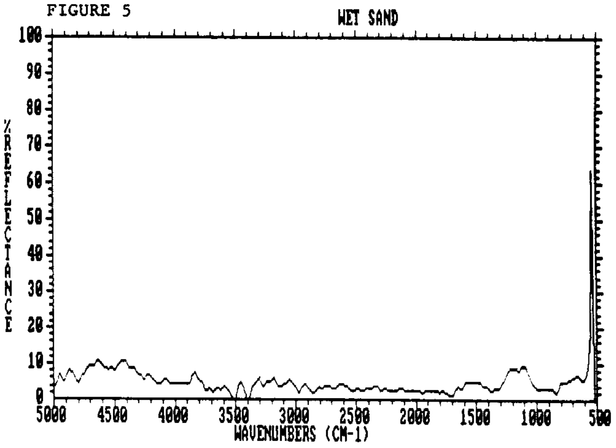

FIGURE 6

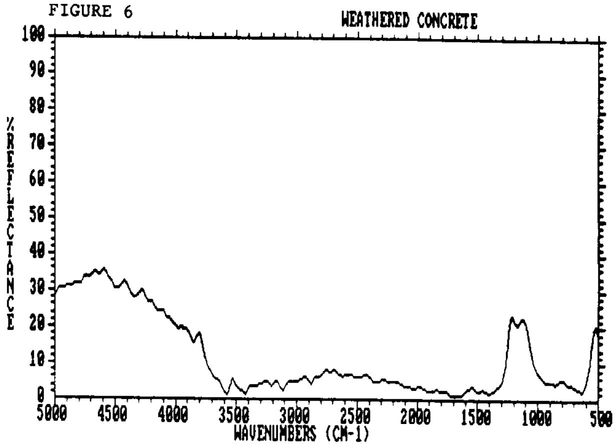

FIGURE 7

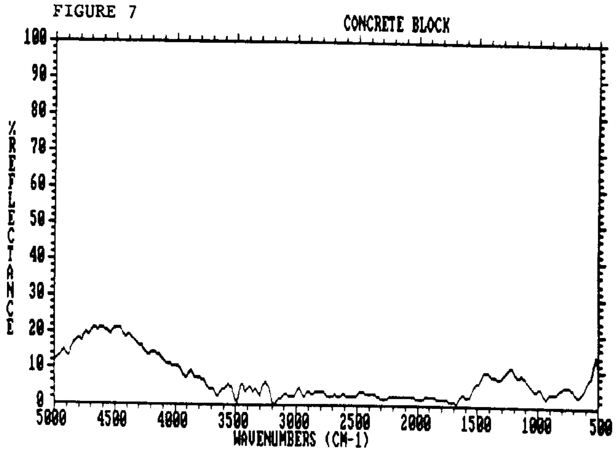

FIGURE 8

TAR

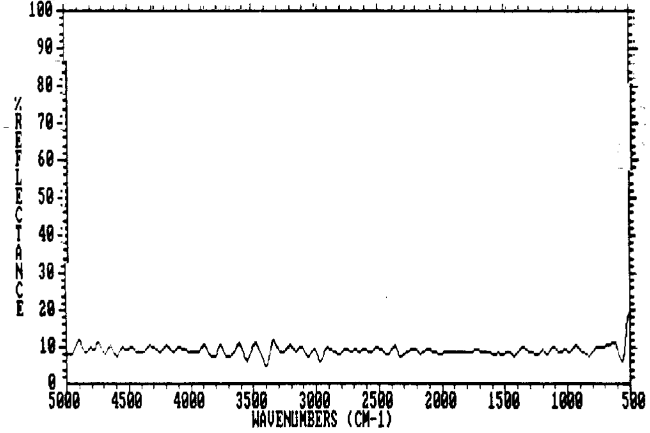

FIGURE 9

"TAR MACK"

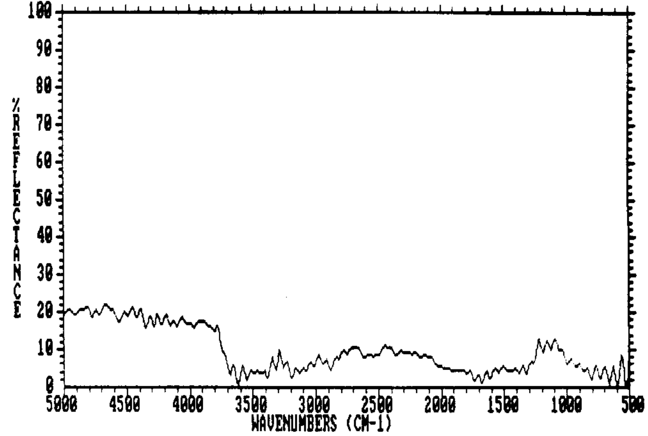

FIGURE 10

CELOTEX WHITE ROOF SHINGLE

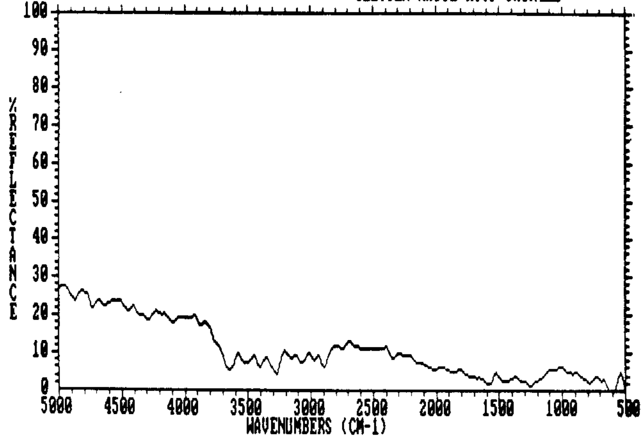

FIGURE 11

ALUMINUM SHEET METAL

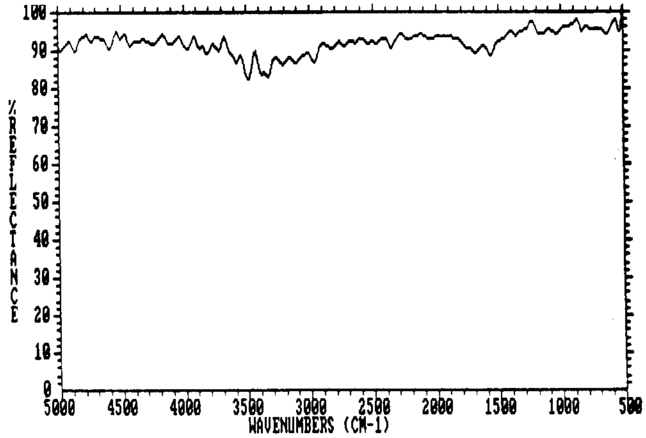

FIGURE 12

4MM OF TAP WATER OVER ALUMINUM

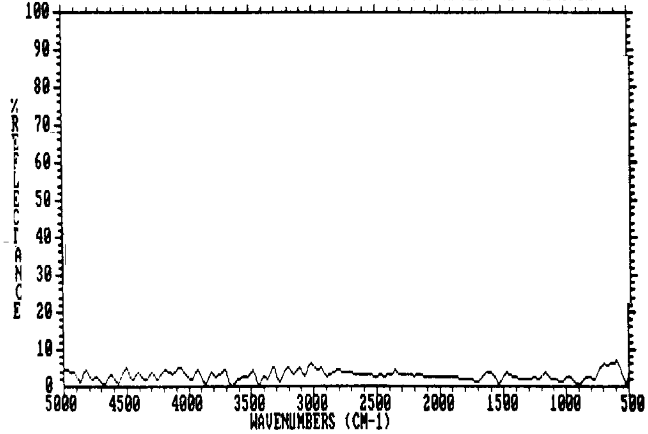

FIGURE 13

ICE CUBE

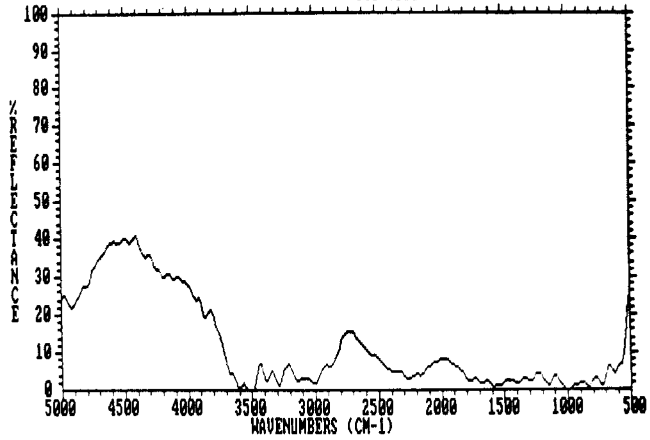

FIGURE 14

BLACK ANODIZED ALUMINUM

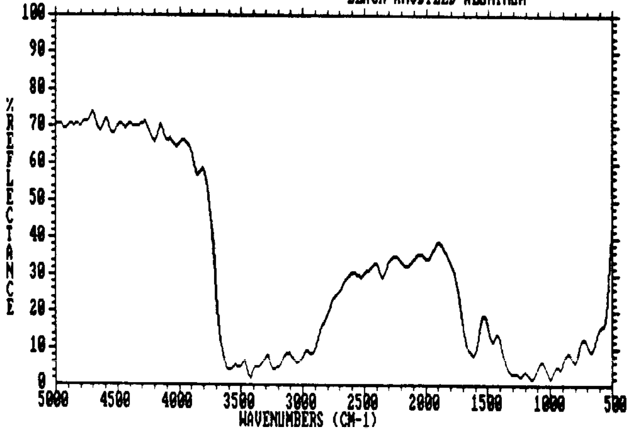

FIGURE 15

SAPPHIRE

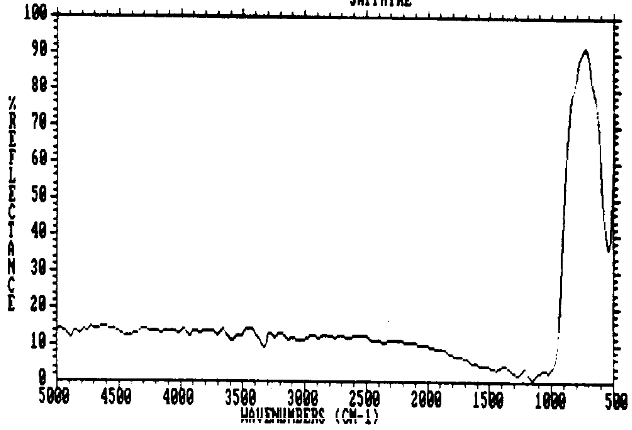

FIGURE 16

MICA SHEET 1.5MM THICK

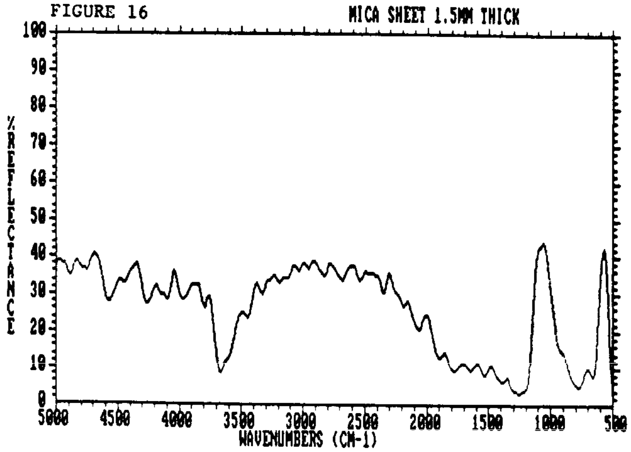

FIGURE 17

QUARTZ ROCK

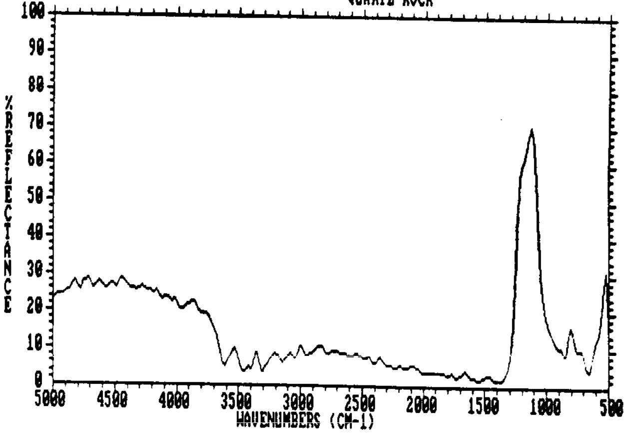

FIGURE 18

FELDSPAR

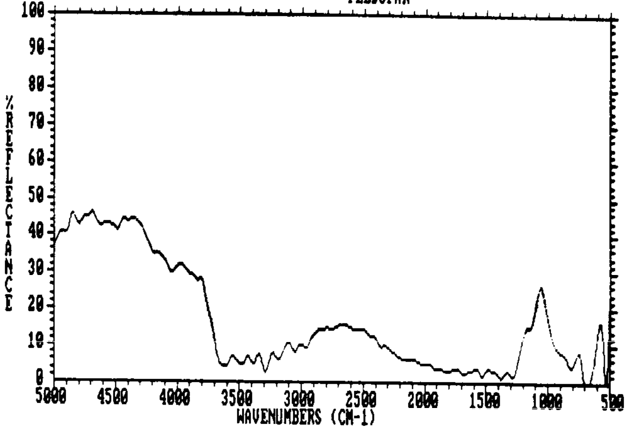

FIGURE 19

DIATOMACEOUS EARTH

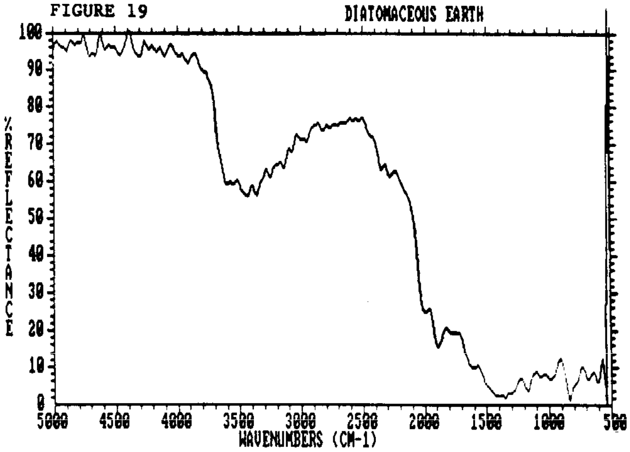

FIGURE 20 CONSTRUCTION 2x8 WOOD

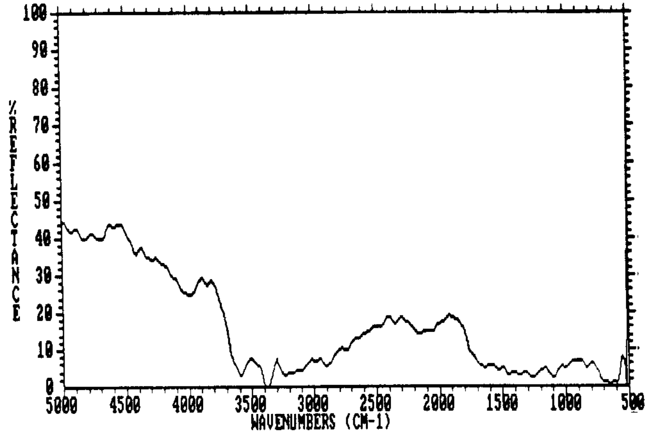

FIGURE 21 FLORIDA LIVE OAK TREE BARK

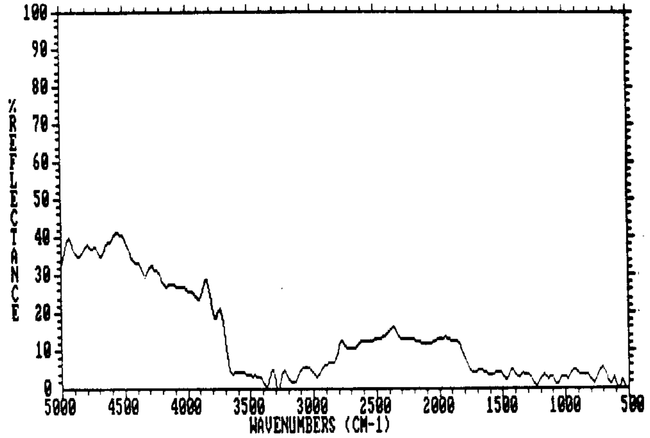

FIGURE 22 SAINT AUGUSTINE GRASS

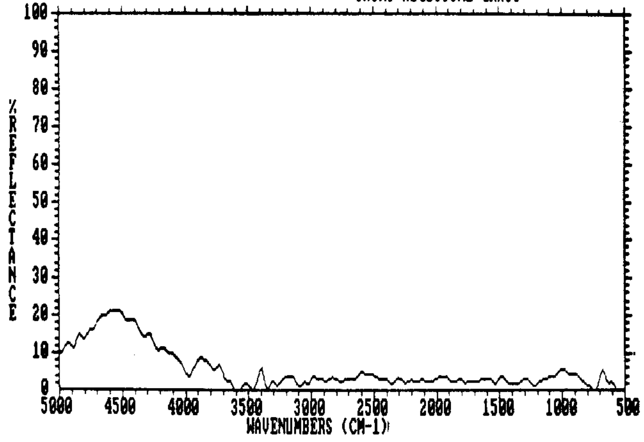

FIGURE 23 LOAM SOIL

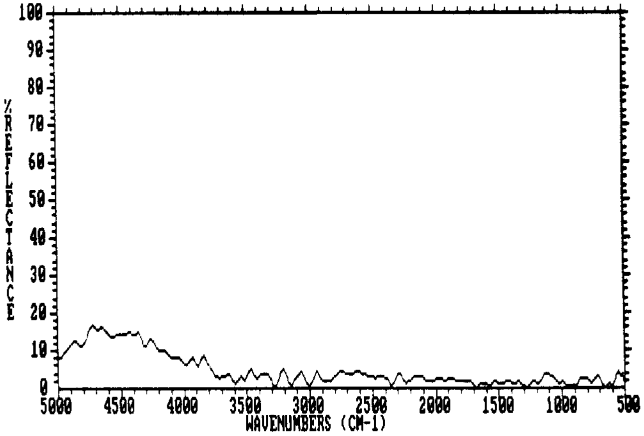

FIGURE 24 GRAPEFRUIT LEAF

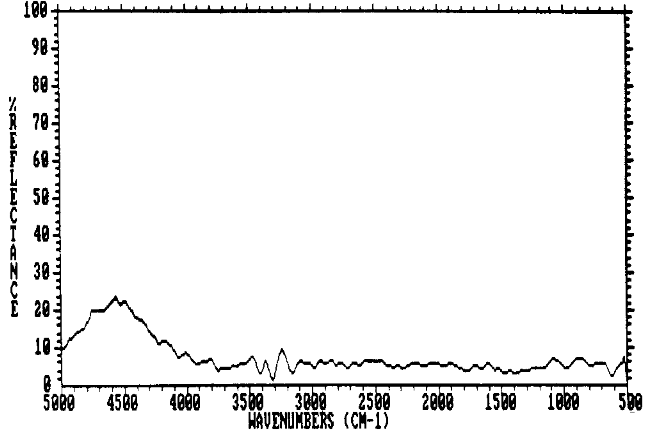

FIGURE 25 MOLD ON GRAPEFRUIT LEAF

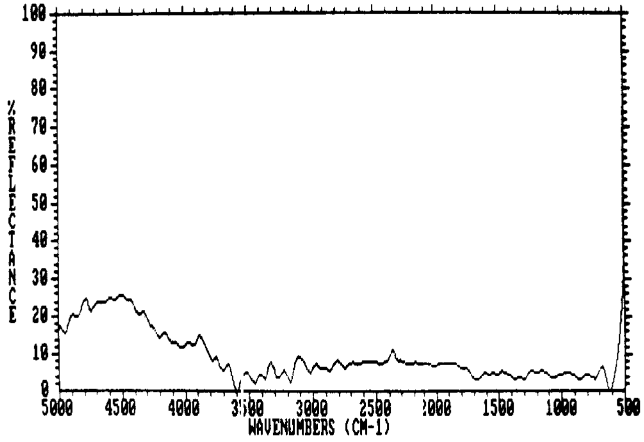

FIGURE 26

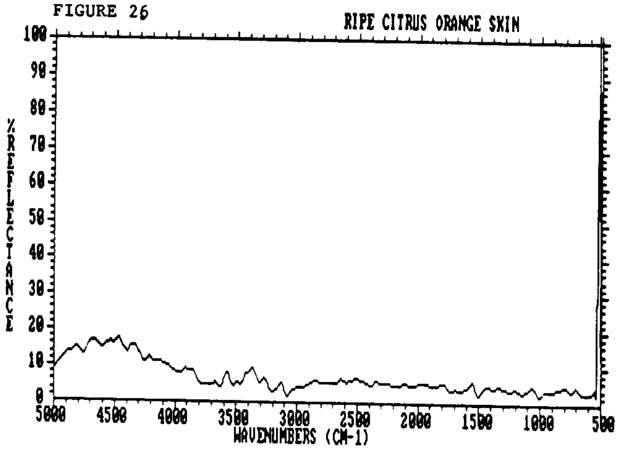

FIGURE 27

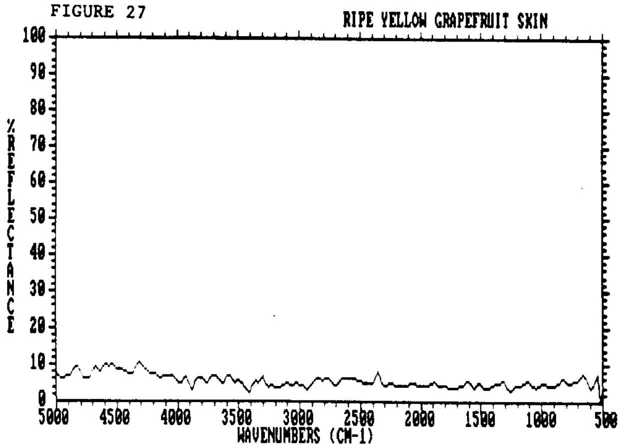

FIGURE 28

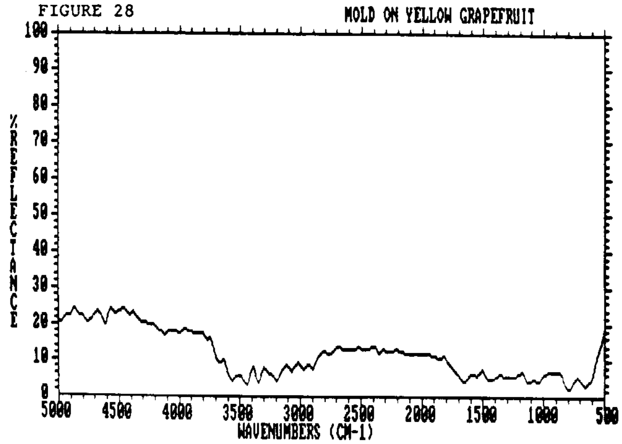

FIGURE 29

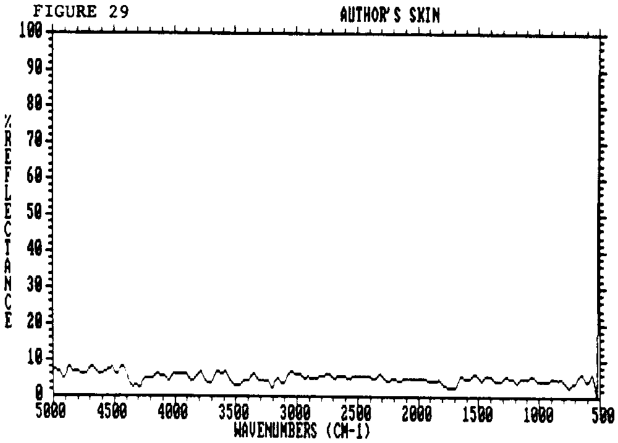

FIGURE 30

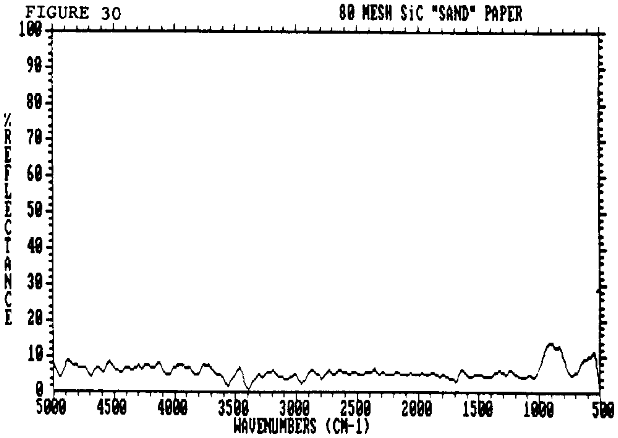

FIGURE 31