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INFRARED TRANSMISSION AND EMISSION OF TEFLON

by

T. Wentink, Jr.† and Walter G. Planet, Jr.‡

AVCO-EVERETT RESEARCH LABORATORY
a division of
AVCO CORPORATION
Everett, Massachusetts

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Los Angeles 45, California

†Now at Avco Research and Advanced Development Division, Avco Corporation, Wilmington, Mass.

‡Now at Barnes Engineering Corporation, Stanford, Connecticut

ABSTRACT

The infrared absorption spectrum of Teflon at 298° K from 2 to 15μ and the surface emission spectrum at a minimum temperature of 700° K from 2.7 to 6.0μ are reported. Corresponding absorption coefficients and emissivity are discussed. The emissivity varies with wavelength in accordance with the absorption, as expected, so that assignment of a color temperature or description of the hot surface as a grey body are not valid.

I. INTRODUCTION

We have reported instrumentation and results from a study of the infrared (IR) emission of quartz.[1] The following is a report of a similar investigation on Teflon[2] under ablating conditions.[3]

The plastic Teflon (polytetrafluoroethylene) is of interest because of its high temperature (for organic materials) stability. The material is very stable, up to 650° K,[4,5] and decomposes rapidly and smoothly in the 700-800° K range.[6] We present here some results on the IR emission spectra of Teflon above 700° K and discuss the emissivity (ϵ).

II. EXPERIMENTAL

The instrumentation and experimental approach were identical to that described previously.[1] Our approach was to record the emission spectra, with the absolute radiation intensity known by comparison with a calibrated black body, and in a spectral region where the assumption of ϵ near unity was made. Thus the true surface temperature could be estimated. Hence, in adjacent spectral regions where the emissivity was clearly less than unity, it can be deduced from the known temperature and absolute intensity.

A study of the IR absorption of Teflon was necessary for interpretation of the emission data. Liang and Krim[7] have reported absorption spectra for films (0.004 to 0.041 mm thickness) in the spectral range 3 to 13μ, and in greater thicknesses from 11 to 140μ. The room temperature absorption spectra of sections (0.013 to 0.76 mm) were measured

in the 2 to 15μ region are shown in Fig. 1. The strong absorption at $\lambda < 3\mu$ is due to optical scattering in the opaque crystalline milky white polymer.

However, above 324° C, a transition temperature, Teflon is optically clear so that this scatter "absorption" is not expected to contribute to the high temperature emissivity. The only significant absorption in thin sections out to about 6μ is that due to a C-F vibrational overtone at 4.2μ. Hence, one would predict in the region 2 to 6μ the emission from Teflon would be characterized by a pronounced peak at 4.2μ.

An emission spectrum of Teflon is shown in Fig. 2. The presence of a sharp peak at 4.2μ is in agreement with the prediction of the emissivity from the absorption spectrum. The absorption noted in the emission spectrum is attributed to CO_2 outside the test chamber. Normally the gases C_2F_4 (the monomer from Teflon decomposition) and CO_2(from C_2F_4 oxidation)[4,6] would be a problem due to the large absorption coefficients of these molecules However, these can be ignored because of the low gas density and short gas path lengths of the test conditions.

III. DISCUSSION

The surface temperature deduced from the emission was 700 ± 30° K, on the assumption of $\epsilon = 1$ at the peak, and no correction for the CO_2 absorption. Both of these approximations tend to lower the calculated temperature and so set a lower bound of the temperature during ablation. The wavelength of measurement is near the black body maximum at the

temperature involved, a situation favorable in determining the temperature from the measured sterradiancy For example, at 4.2μ the black body radiation increases a factor of 2 in going from 650 to 750° K. Hence, the experimental error in the temperature is expected to be small.

However, the assumption of $\epsilon = 1$ is more fraught with uncertainty. This is particularly questionable if, as is indeed expected, the low conductivity of Teflon will make for large temperature gradients below the surface, i.e. the radiating surface of interest is very thin and the transmission becomes appreciable. Then the assumption is poor, and the measurement interpretation becomes more complicated. Thus, a more desirable experiment is to measure the emission of the band at 8-9μ, where the emissivity assumption is better. (See Fig. 1.)

The scatter effect in the transmission spectra at the shorter wavelengths prevents accurate calculation of absorption coefficients (α), although we have estimated such near the absorption band at 4.2μ. The data fit in most cases the usual expression $I/I_o = \exp(-\alpha\ell)$. These coefficients are 9.08 and 1.61 (in mm^{-1}) at the peak and lowest absorption wavelengths, 4.2 and 4.8μ, respectively. Beyond 5 microns the data should permit a better determination of the coefficients. Some typical values are 4.90, 2.60, and 12.15 (in mm^{-1}) at 5.6, 6.1, and 7.5μ, respectively.

An estimate of the surface layer thickness needed to give an ϵ close to 1.0 can be made with the approximation that the α is insensitive to temperature. Thus, at 4.2μ where $\alpha = 9.08\ mm^{-1}$, $\ell = 0.1$, 0.2, and 0.5 mm correspond to transmission of 40, 16, and 1%. It is tempting

to estimate an emissivity for our case. However, the temperature distribution normal to the surface under our test conditions is sufficiently uncertain (the average ablating layer thickness 0.2 to 0.5 mm) so that we refrain from this estimate and corresponding correction to the measured minimum temperature.

The ablation[3] of the Teflon models, monitored with motion pictures, proceeded smoothly and with no indication of a liquid layer. The surface temperature measured and general behavior observed are in qualitative agreement with the mechanism of pyrolysis and decomposition temperatures given by Siegle and Muus[4] and Madorsky et al,[6] especially in view of the great difference in heating rates between their and our experiments. The temperature for "rapid and complete" decomposition of Teflon to the monomer is given as 780° K by Madorsky. Our data are reasonable if we assume there is equilibrium at the surface during ablation.

Since completion of the present set of experiments we have learned of several results that indicate the temperature of ablating Teflon is in the 900-1,000° K range. Jennings and Easton[8] have calculated a surface temperature 833° K to 1127° K at heating rates of 1 Btu/sec ft^2 to 1,000 Btu/sec ft^2, and cite the pyrometer measurement of Zirinsky[9] of 922° K (in a cyanogen-oxygen flame at 450 Btu/sec ft^2). Our heating rate was approximately 1,000 Btu/sec- ft^2. The most extensive work known to us is that of Hanst,[10] which is based on measured spectral emissivity and covered the 8-9μ band. This gives temperatures in the 950-1,000° K range.

Thus, calculation of the emissivity in the IR region from our data is not warranted, since our operating true temperature is not known sufficiently accurately. However, the most important result is confirmation that the surface emissivity of Teflon varies with wavelength in accordance with the absorption spectrum. Thus nonspectral measurements leading to a "color" temperature can be misleading, i.e. treatment as a grey body is not justified.

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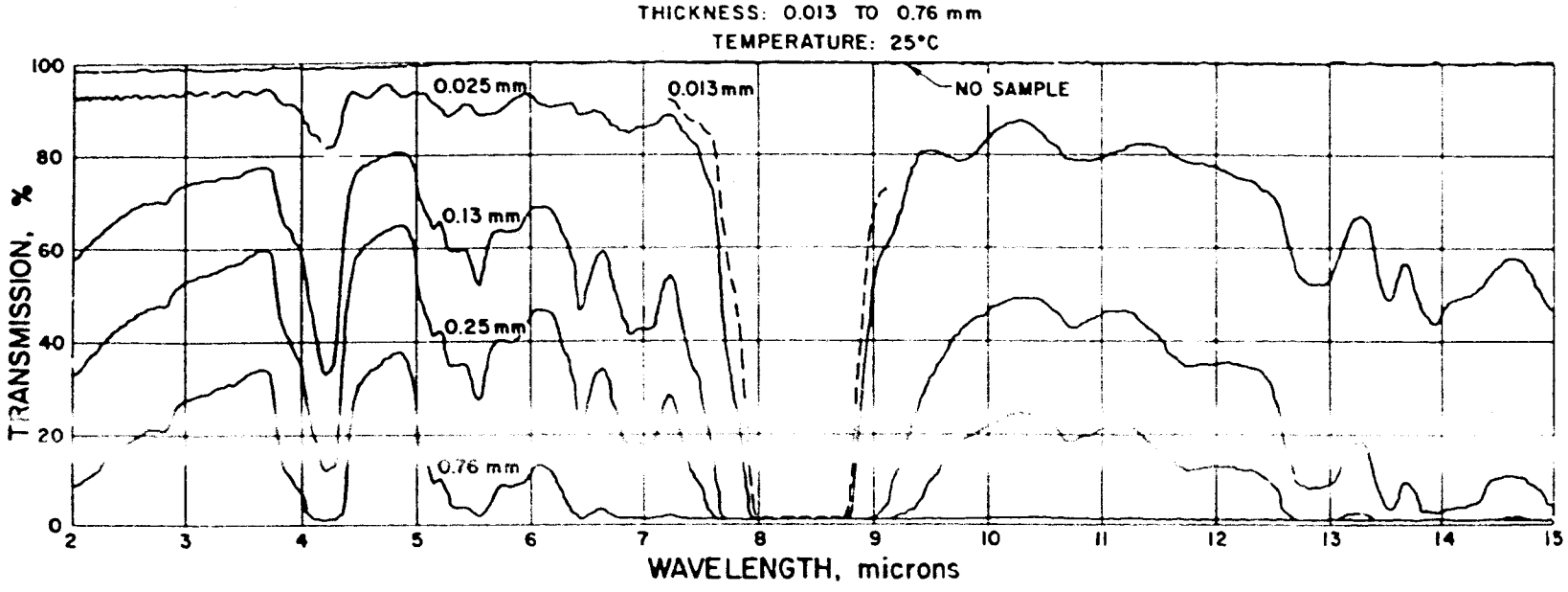

Fig. 1 IR transmission of Teflon (room temperature). (The 0.025 mm sample was cast film and transparent in the visible; the thicker samples were "skived" (shaved) from bulk, milk-white stock and opaque in the visible.)

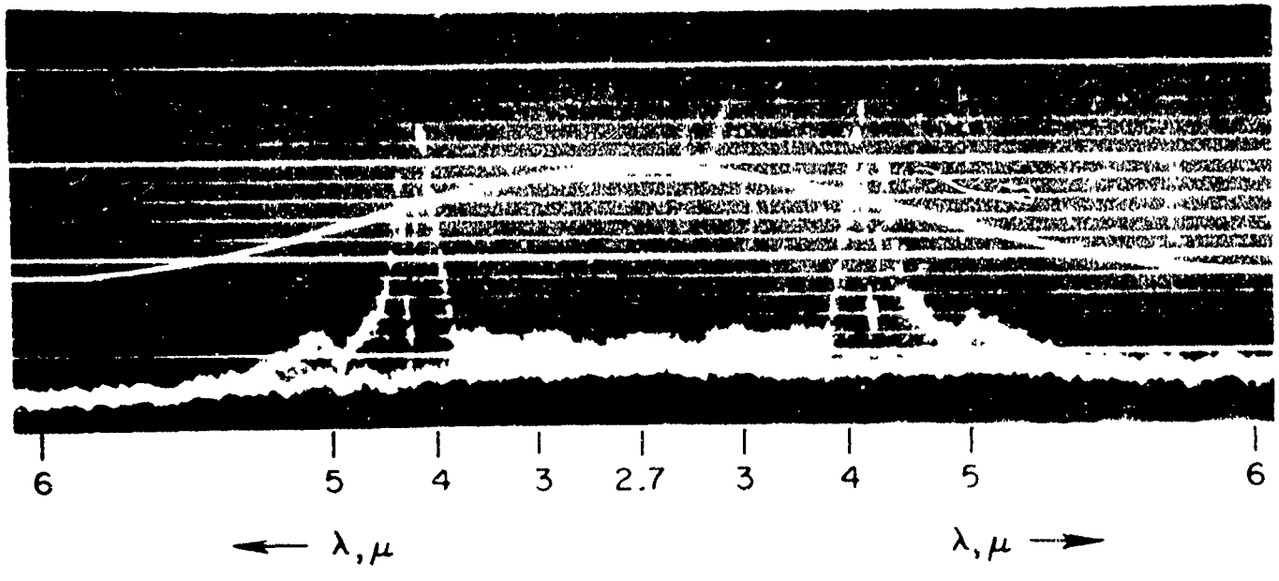

Fig. 2 IR emission spectrum of Teflon (Au-Ge detector; Al_2O_3 window; CaF_2 spectrometer prism; 0.1 volts/large division).

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2. For convenience and briefness we use Teflon loosely as a generic term. However, it should be noted that Teflon is the registered trademark of the DuPont Company, covering fluorocarbon resins. These include the TFE-fluorocarbon resins (polymers of tetrafluoroethylene) and FEP-fluorocarbon resins (copolymers of hexafluoropropylene and tetrafluoroethylene). Here we deal only with the TFE-resins.

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