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Research and Development Report

HEMISPHERICAL SPECTRAL EMIT-
TANCE OF THULIUM OXIDE

by

R. K. Stewart, W. R. McMahon, and
D. R. Wilder

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HEMISPHERICAL SPECTRAL EMITTANCE OF THULIUM OXIDE

R. K. Stewart, W. R. McMahon, and D. R. Wilder

ABSTRACT

Hemispherical spectral emittance values, ranging between 0.7 and 0.8, are given for Tm_2O_3 over the temperature interval of 2300° to 3000°K. In this interval emittance is linear with respect to temperature and is nearly horizontal. A carbon arc image furnace and a photocell detector were employed to obtain the data reported.

INTRODUCTION

Emittance is defined¹ as the ratio of radiant energy emitted by the material to the radiant energy emitted by a blackbody at the same temperature, surface condition, and geometry. Emittance is a property of the specimen and may be influenced by such things as size and surface condition.

This experiment is concerned with emittance and should not be confused with emissivity which is a property of the material only and is defined¹ as the ratio of radiant energy given off by an opaque body with a polished surface to the radiant energy given off by a blackbody, both at the same temperature, surface condition, and geometry.

Most reported emittance data varies from one experimenter to another. Some of the variables that might affect emittance data² are:

thermal history, surface condition, porosity, grain size, and purity. Richmond³ has shown that surface roughness on ceramic materials does not affect the emittance to a measurable degree.

PRINCIPLES OF METHOD

Essentially the method described by Comstock⁴ was used to determine the hemispherical spectral emittance. The basic equation of radiation for all materials is

$$\epsilon + r + t = 1 \quad (1)$$

For an opaque body, the transmittance term is zero, giving

$$\epsilon + r = 1 \quad (2)$$

From Eq. (2), Comstock suggests measuring the ratio of reflectance to incident radiation

$$\epsilon = 1 - K(R/I) = 1 - K \left(\frac{(R+E) - E}{I} \right) \quad (3)$$

where

ϵ = the hemispherical spectral emittance of the sample

R = the intensity of the reflected light from the sample

E = the intensity of the emitted light from the sample

I = the intensity of the incident light from the arc

K = a combined constant accounting for optical losses such as dust on the imaging mirrors, losses through the lightpipe and focusing losses.

K is determined before each series of runs for a given filter. This is done by a MgO smoked copper surface (water cooled) which has a reflectivity of 0.98.⁵ That is

$$K = (I/R) (.98) \quad (4)$$

where

I = the intensity of the incident light from the arc

R = the intensity of the reflected light from the sample.

Equations (3) and (4) combined give the spectral emittance values.

The brightness temperature, corresponding to emittance value, is computed from a calibration curve (for the particular filter) and the amplitude corresponding to a millivolt photocell output of the emittance curve E of the oscilloscope photograph. The true temperature is computed from Weins equation

$$\ln \epsilon_{\lambda} = \frac{\epsilon_2}{\lambda} \left(\frac{1}{T} - \frac{1}{T_b} \right) \quad (5)$$

where

T = true temperature °K.

T_b = brightness temperature °K.

INSTRUMENTATION AND CALIBRATION

The carbon arc image furnace employed was constructed with a rotating lightpipe (relaying light to the photocell) and a chopper. The lightpipe and chopper were synchronized so that the photocell was able to "see" the following sequence of events: 1) incident radiation I from the carbon arc; 2) reflected plus emitted radiation, $R+E$, from the sample; 3) the incident radiation I , again; and finally 4) the emitted radiation, E . All of the radiation events were relayed from the photocell to a Tektronics oscilloscope where they were photographed by a Polaroid camera.

Information was relayed to the oscilloscope as soon as the sample was exposed to the carbon arc radiation. Exposure time varied from 2 to 5 sec depending on the oscilloscope sweep rate.

To calibrate the linear Hoffman Solar Cell 51C, a plot of photocell output vs reciprocal brightness temperature was made for each Wratten filter. This photocell had a spectral response of 0.4 to 1.15 μ with a peak response at 0.85 μ . Since the Wratten filter was transparent to radiation beyond 0.7 μ , an infrared filter was used. The "window opening" for the Wratten filters with the infrared filter was verified on the Cary 14 spectrophotometer. From the principles of radiation⁷ a plot of logarithm photocell output vs $1/T^\circ\text{K}$ gives a straight line similar to one in Fig. 1.

Fig. 1. Plot of photocell out put (millivolts) vs brightness temperature of the projection lamp by an optical pyrometer.

This is the graphical form of Eq. (6):

$$\log(mv) \propto \frac{\epsilon_{\lambda} C_1}{\lambda^5 e^{C_2/\lambda T_b}} \quad (6)$$

where C_1 = Planck's first radiation constant

C_2 = Planck's second radiation constant

T_b = brightness temperature °K

λ = effective wavelength of Wratten filter

ϵ_{λ} = spectral emittance of the light source material.

The brightness temperature was taken with a micro-optical pyrometer and at the same time a photocell output was relayed to the oscilloscope and photographed. The lamp used to obtain these brightness temperatures was a GE-CPR projection lamp.

SAMPLE PREPARATION

Thulium oxide rods of 3/8 in. diam and about 1 in. length were pressed to 600 lb (5430 psi), then hydrostatically to 50,000 psi. The thulium oxide (of 325 mesh) came from the Ames Laboratory and was 99.5% pure. No binder was used to press the material. The density was 55 to 65% of theoretical density.

RESULTS AND DISCUSSION

Emittance vs temperature plots are shown in Figs. 2-8, and emittance vs wavelength in Fig. 9. An example of the oscilloscope amplitudes of the radiation events recorded by the polaroid photograph is shown in Fig. 2.

Fig. 2. Photograph of oscilloscope screen plotting photocell output (10mV/cm) vs time (0.2 sec/cm). The top line shows the incident radiation from the arc, I. The middle line is the reflected plus emitted radiation R + E, from the sample. The bottom line is the emitted radiation, E, from the sample.

A problem arose in the calibration process. It was found quite often when plotting reciprocal brightness temperature vs the logarithm of the photocell output for each filter that a slight curve rather than the expected straight line resulted. Another problem related to the curved line was an unexpected slope. Since the effective wavelength was already known for each filter, the slope was predictable, (slope = $\frac{\text{constant}}{\lambda_{\text{effective}}}$), but a difference resulted by drawing the predicted slope (corresponding to $\lambda_{\text{effective}}$ of the filter) and least squares fit through the curve. This is shown in Fig. 3.

Fig. 3. Logarithm of photocell output from projection lamp vs reciprocal temperature for the calibration of a filter. This plot shows a typical curve obtained rather than the theoretical straight line. This plot also shows the difference between the slope predicted from the filter and the experimentally observed slope.

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Fig. 4. Hemispherical emittance vs temperature for Tm_2O_3 using a 70 Wratten filter (effective $\lambda = .676\mu$).

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Fig. 5. Hemispherical emittance vs temperature for Tm_2O_3 using a 72B Wratten filter (effective $\lambda = .605\mu$).

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Fig. 6. Hemispherical emittance vs temperature for Tm_2O_3 using a 73 Wratten filter (effective $\lambda = .575\mu$).

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Fig. 7. Hemispherical emittance vs temperature for Tm_2O_3 using a 74 Wratten filter (effective $\lambda = .539\mu$).

Fig. 8. Hemispherical emittance vs temperature for Tm_2O_3 using a 75 Wratten filter (effective $\lambda = .488\mu$).

Fig. 9. Plot of hemispherical emittance vs wavelength for thulium oxide at 2500°K.

One possible reason for a curve as shown in Fig. 3 is perhaps the intensities at the high and low temperatures were out of the photo-cell's linearity region.

From the condition of the sample after the emittance run, it was apparent that the surface had been molten and semitransparent as shown in Fig. 10.

The Tm_2O_3 rods were used for several emittance measurements so that the starting surface was glassy and semitransparent; however, no difference was observed for the glassy surface and the cleanly pressed powdered surface.

Fig. 10. Photograph of samples after emittance run. Starting samples looked like this also.

This semitransparent area varied from 1 to 3 mm in depth. Thus, there was a different phase and opaqueness just below the surface of the sample, and it may not be entirely justified in using the assumption that the transmittance term is zero. However, McMahon⁶ explains that even though the material is molten on the surface and has a translucent region, this does not alter the reflectance to a significant degree, nor is the transmittance changed from zero.

As shown in Figs. 2-8 there are several lines of emittance vs temperature for a given wavelength, rather than one. This is because each measurement represented appeared equally valid. About 5 or 6 measurements were made for each wavelength. Reported data was taken only from the photographs showing the best stability of the incident arc radiation.

The spread of emittance values given for a particular wavelength indicates that reproducibility for this experiment was about $\pm 10\%$.

The slopes were sufficiently different that a temperature difference of 30° to 40°K resulted for a given reading of the logarithm of the photocell output. But the plots of emittance vs temperature were so nearly horizontal that the temperature error of 40°K did not affect the results to a very large degree.

CONCLUSIONS

- 1) Hemispherical spectral emittance values are given for fused Tm_2O_3 over the temperature interval of 2300° to 3000°K , with a reproducibility of $\pm 10\%$.

2) The hemispherical spectral emittance of fused Tm_2O_3 is high, ranging from approximately 0.7 to slightly above 0.8, over the range 2300° to 3000°K.

3) The hemispherical spectral emittance of fused Tm_2O_3 is linear (nearly horizontal) with respect to temperature over the temperature interval of 2300° to 3000°K.

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