Emissivity measurement of high-emissivity black paint at CENAM

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To measure the temperature of the surface of an opaque object by radiation thermometry, it is necessary to know its surface emissivity. High-emissivity black paint can be applied to the inner walls of a cavity to be used as a blackbody radiator. It can also be applied to some highly reflecting metals so that their temperature can be estimated by radiation thermometry.
In this work, it is described the emissivity measurement of high-emissivity black paint that has been used for the two applications described above. The average emissivity of the measured paint in the 8 to 14 micrometers wavelength range was estimated as 0.972 $\pm$ 0.012. The results obtained may be of use for those using the paint at temperatures from 50 to 150°C.

Keywords: Spectral emissivity; radiation thermometry.

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1. Introduction

A radiation thermometer, RT, is defined as a radiometer calibrated to indicate the temperature of a blackbody [1]. The RT receives radiation from the blackbody and generates an output signal which, through a calibration algorithm, is used to provide a measure of blackbody temperature. It is important to notice that the calibration process is based upon the radiation coming from a blackbody that has the unique characteristic of a known relationship (Planck´s law) between the spectral radiance and the temperature.

The practical applications of radiation thermometry are related with measuring the temperature of targets that are not blackbodies. The central problem of radiation thermometry is how to infer the temperature of a non-black target, in the presence of surroundings at different temperature, from the radiance temperature indicated by a calibrated RT.

Then, two practical applications arise. The first one is to build a radiation source that can be used as a blackbody for calibration purposes. The second is to measure temperature of a non-black target. For both applications, it is required to now the emissivity of materials.

In this work, it is described the emissivity measurement of a commercial high-emissivity black paint [2] that has been used at CENAM for the two applications described above: to cover the inner walls of a blackbody cavity for calibration of infrared ear thermometers [3], and as an aid to measure surface temperature of some highly reflective metals. The results obtained may be of use for those designing blackbodies working at temperatures from 50 to 150°C, and those trying to measure highly reflecting surfaces where they can apply some paint to be able to measure their temperature by radiation thermometry. Reference [4] provides information on other coatings frequently used for blackbodies.

2. Emissivity measurement system at CENAM

Figure 1 shows the experimental setup for emissivity measurement being developed at CENAM. The setup has four main components. The first one is a Fourier transform infrared spectrometer, FTIRS, Nicolet model 6700. It has a DTGS detector with KBr window, two gold coated mirrors, and a KBr beamsplitter. For the measurement, spectra are collected in the spectral range from 400 cm^{-1} to 2000 cm^{-1} (5 μm to 25 μm) with a resolution of 2 cm^{-1} and 256 scans.

The second main component is an optical system that collimates radiation from the sample to the spectrometer. Radiation is collimated with one elliptic and one parabolic concave mirror. The first mirror focuses the image of the sample on a circular aperture that limits the detected area. The second mirror collimates the radiation, passing through the aperture, into the spectrometer.

The third component is a reference blackbody radiation source: a blackbody cavity immersed in a liquid bath. The temperature uniformity of the cavity is $\pm\ 0.25$°C at 150°C.

The fourth component is an electrically heated aluminum block with metal clips that keep the sample in place. A controller regulates the temperature of the aluminum block within $\pm\ 0.1$°C during measurement time. The block with the sample is placed inside a cylindrical enclosure that acts as an isothermal surrounding kept at laboratory temperature.

To obtain the radiation spectra, the sample and the blackbody are alternately positioned in the focus point of optical system that guides the radiation to the FTIRS.

3. Samples

The samples consisted of three copper disks with 50 mm diameter and 5 mm thickness. The copper disks were cleaned with acetone, and three coatings of primer and three coatings of paint were applied to one of their surfaces. There was a

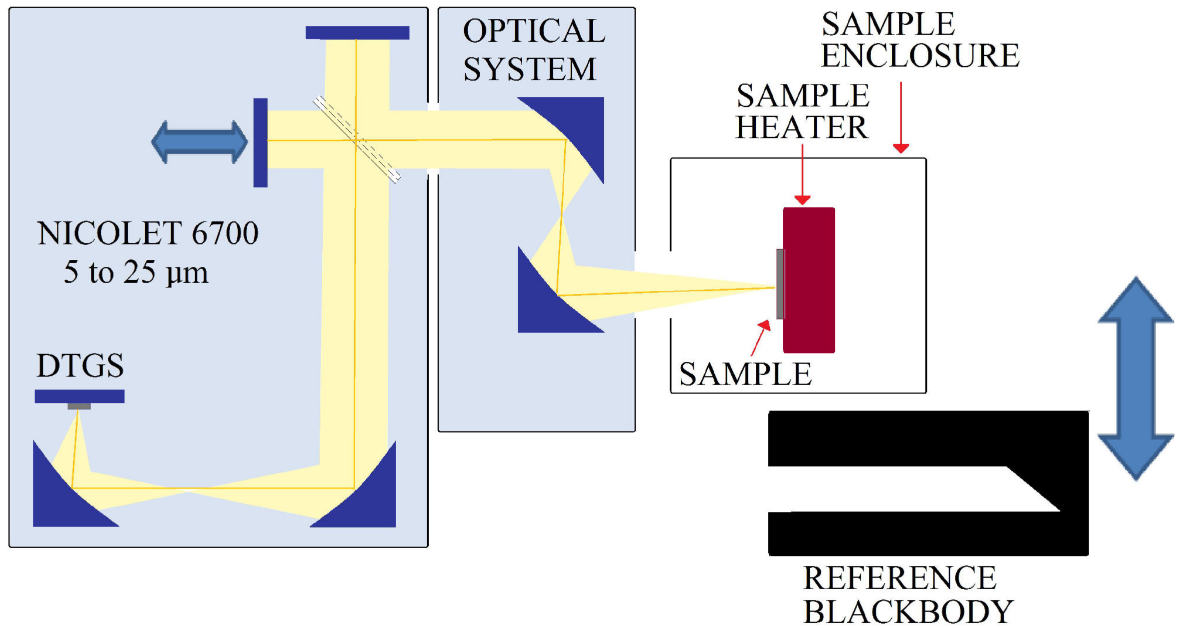

FIGURE 1. Experimental setup for emissivity measurement at CENAM.

24 hour drying period between coatings. The samples were baked at 175°C for 24 hours previous to the emissivity measurement.

4. Measurement equation

The basic measurement of spectral emissivity is made in the following fashion. It is employed the common practice of performing three measurements: along with the particular sample, two "known" blackbodies at different temperatures (typically one near to that of the sample and one near ambient) are measured [4,5]. The second blackbody is used to subtract out the radiance component from the measurement system itself. The spectral emissivity of the sample is then given by Eq. (1)

$$\varepsilon_{\nu,T_M;M} = \varepsilon_{\nu,T_B;B} Re\left[\frac{S_{\nu,T_M;M} - S_{\nu,T_{AM};B}}{S_{\nu,T_B;B} - S_{\nu,T_{AM};B}}\right] \times \left[\frac{L_{\nu;B}(T_B) - L_{\nu;B}(T_{AM})}{L_{\nu;B}(T_M) - L_{\nu;B}(T_{AM})}\right] \quad (1)$$

Where,

$\varepsilon_{\nu,T_M;M}$ Spectral emissivity of sample at temperature T_M

$\varepsilon_{\nu,T_B;B}$ Spectral emissivity of blackbody reference at temperature T_B

$S_{\nu,T_M;M}$ FTIRS complex measured spectrum corresponding to sample a temperature T_M

$S_{\nu,T_B;B}$ FTIRS complex measured spectrum corresponding to blackbody reference at temperature T_B

$S_{\nu,T_{AM};B}$ FTIRS complex measured spectrum corresponding to blackbody reference at ambient temperature T_{AM}

$L_{\nu;B}(T)$ Spectral radiance of blackbody (Planck law) a temperature T

For the experiment T_M and T_B were varied from 50 to 150°C, and T_{AM} was kept at 23°C. The measurements were performed in repeated sequence (blackbody at high temperature-sample-blackbody at low temperature-sample-blackbody at high temperature) to reduce effects of drift.

5. Uncertainty analysis

The following influence variables were taken into account for the uncertainty analysis:

The size-of-source effect of the set spectrometer-optical system was measured and it was found that practically all radiation the spectrometer detector receives comes from a 20 mm diameter circular area centered at focusing point in the center of the 50 mm-diameter sample [6]. So in this case, no correction due to this effect was required.

EFTIR linearity was measured by a superposition method and its contribution to uncertainty was estimated as 0.13°C.

The effective emissivity of the blackbody is 0.9994 ± 0.0002 and it was estimated from the inner walls emissivity and the geometry of the cavity.

The blackbody cavity temperature was measured with a calibrated platinum resistance thermometer, PRT, whose sensing part was approximately 2 mm near the bottom of the cavity.

TABLE I. Main contributions to combined uncertainty.

Main contributions to combined uncertainty	Sub-components	Type	Contribution to combined uncertainty (%)
Spectral emissivity of blackbody		B	3
Temperature of reference blackbody			30
	Calibration of PRT	A	
	Repeatability	A	
	Sensibility	A	
Temperature of sample surface			43
	Calibration of PRT	A	
	Repeatability	A	
	Sensibility	A	
Measured signal of spectrometer[a]			24
	Repeatability	A	
	Nonlinearity	B	

[a] Includes contributions due to temperature and directional spectral emissivity of enclosure and detector.

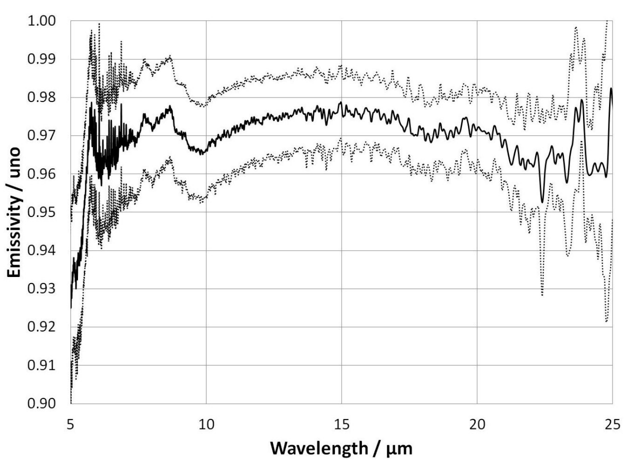

FIGURE 2. Spectral emissivity and uncertainty of high-emissivity black paint in the range from 5 to 25 micrometers.

The temperature of the samples is measured with a calibrated small contact thermometer, PT100 type, placed approximately 2 mm below the radiating surface of the coating. The thermometer was calibrated in the -39 to 232°C range with a combined uncertainty less than 0.006°C. As the thermometer is inside the substrate (copper), there is a difference between the temperature measured with the contact thermometer and the coating surface temperature. The thickness and thermal conductivity of the coating are 0.37 ± 0.5 μm and 0.75 ± 0.25 $Wm^{-1}K^{-1}$ respectively, so a 0.86°C temperature difference was estimated between temperatures measured with PT100 and coating surface temperature at around 150°C.

The distance from detector to sample was less than 150 cm so the absorption and emission effects from the atmosphere were negligible.

The measurement requires that the sample and the blackbody are alternately positioned in the focus point of the FTIRS. The repeatability on the position was better than 0.5 mm, and no difference in radiance signal was found for lateral displacing of the measurement point up to 5 mm.

Laboratory conditions during measurements: 23.0 ± 0.5°C and 45 ± 5 RH.

6. Results and application example

Figure 2 shows the experimental result (directional spectral emissivity of the paint), and its uncertainty, in the range from 5 to 25 micrometers.

Table I shows the main contributions to combined uncertainty. It can be seen that the higher contributions were due to sample and blackbody temperatures. To lower the combined uncertainty, CENAM is presently working on improving the heater and the heater control as well as on improving the reference blackbody. CENAM is also working on extending its measurement capacity to include measurement of directional spectral emissivity at different angles.

From the results, the average emissivity of the measured paint in the 8 to 14 micrometer wavelength range, which is a common working wavelength range of low and medium temperature RTs and thermal imagers, is 0.972 ± 0.012, in the range from 50 to 150°C.

6.1. Example on the use of the measured average emissivity ε

The effective emissivity of a blackbody formed by an isothermal spherical cavity of radius R, aperture of radius r, and wall emissivity ε can be estimated from Eq. (2), [1]

$$\varepsilon_{EF} = \frac{2\varepsilon}{\varepsilon\left(1+\sqrt{1-\frac{r^2}{R^2}}\right)+1-\sqrt{1-\frac{r^2}{R^2}}} \qquad (2)$$

If the inner walls of such cavity, with $R = 10.0 \pm 0.2$ cm and $r = 2.0 \pm 0.2$ cm, are covered with the measured black paint with $\varepsilon = 0.972 \pm 0.012$, its effective emissivity would be 0.9997 ± 0.0001, in the 8 to 14 micrometer wavelength range.

7. Conclusion

The spectral emissivity of a commercial black paint measured with the experimental setup developed at CENAM was presented.

From the result, it was estimated that the average emissivity of the black paint, in the 8 to 14 micrometers wavelength range, was 0.972 ± 0.012, for temperatures from 50 to 150°C.

An example on the use of the average emissivity result to estimate the effective emissivity of a spherical blackbody was provided.

Note

Reference to commercial product is provided for identification purposes only and constitute neither endorsement nor representation that the item identified is the best available for the stated purpose.

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