Devices & Services Co.

Technical Note 79-17

EMISSIVITY MEASUREMENTS FOR IN-PLACE SURFACES AND FOR MATERIALS WITH LOW THERMAL CONDUCTIVITY

The standard emissivity measurement with the Devices and Services Model AE Emissometer is made by direct comparison with a sample of known emissivity. (See Technical Note 78-2). This requires that the two samples be maintained at or near the same temperature. A heat sink, provided with the instrument, performs this function for small flat samples that can be mounted alongside the standard. This technical note describes procedures for measuring the emissivity of surfaces in cases where a constant surface temperature cannot be maintained. These include thick or thermally insulating materials where the surface temperature will rise due to heat input from the detector, for surfaces that have to be measured in place, and large pieces which cannot be placed on the heat sink.

Background

For the usual emissivity measurement, the Emissometer is placed on the sample as shown in Figure 1.

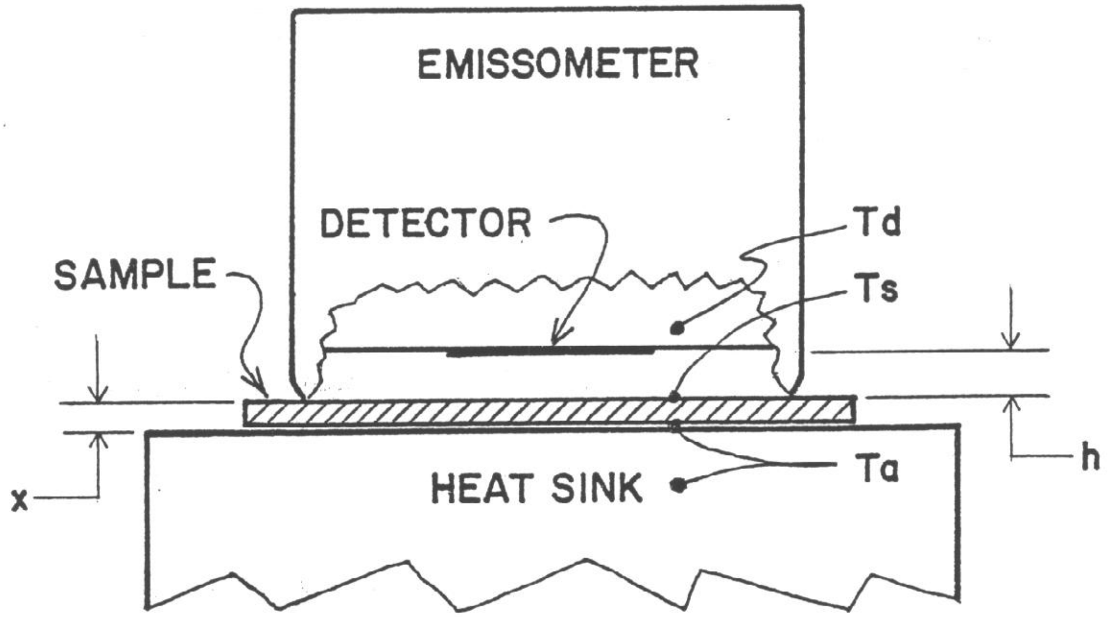

FIGURE 1

The thermopile detector is mounted in an aluminum heat sink that is electrically heated to a constant 180°F. The standard or sample is placed on the 4" x 6" heat sink that maintains both the standard and the sample at a temperature near ambient. Because there is a radiation heat input to the sample, the temperature at the surface of the sample will begin to rise immediately when the detector is moved in place. The temperature rise across the sample depends on the thermal conductivity and the thickness of the material. If the surfaces of the sample and the standard are not at the same temperature when the detector reading reaches a steady value, some error will be introduced into the measurement. Assuming steady state conditions are achieved, this error can be estimated. The detector is a differential thermopile that, in the Emissometer AE configuration, responds only to the radiation heat transfer between the sample and the detector surface. The output of the detector can be expressed as:

$$D = K\varepsilon\ (Td^4 - Ts^4) \tag{1}$$

where, K is a detector constant
D is the output in arbitrary units
and ε is the emissivity of the sample

It will be assumed that the standard and ambient temperatures are equal, and all of the error is due to the temperature rise across the sample whose emissivity is unknown. In order to find Ts, an energy balance is made at the surface of the sample.

$$\frac{k}{x}(Ts - Ta) = \frac{\sigma\ (Td^4 - Ts^4)}{\frac{1}{\varepsilon} - 1 + \frac{1}{\varepsilon d}} + \frac{ka}{h}(Td - Ts) \tag{2}$$

where, k is the thermal conductivity of the sample
x is the sample thickness
σ is the Stephan-Boltzman constant (0.173×10^{-8} Btu/hr $ft^2(°R)^4$)
ε is the sample emissivity
εd is the average emissivity of the detector and detector heatsink
ka is the thermal conductivity of air
h is the length of the air space between the sample and detector

For the Emissometer,

$$Td = 640R;\ Ts \cong Ta = 535R$$
$$h = 0.17\ \text{in.};\ \varepsilon d = 0.93$$
$$ka = 0.016\ \text{Btu/hr ft F}$$

$$Ts - Ta = \frac{x}{k}\left[\frac{148.5}{1/\varepsilon + .0753} + 119\right]$$

$$Ts - Ta \cong \frac{x}{k}\ (150\varepsilon + 120) \tag{3}$$

From Equation (1), the error in the detector output is,

$$E = K\varepsilon\ (Td^4 - Ta^4) - K\varepsilon\ (Td^4 - Ts^4)$$

$$E = K\varepsilon\ (Ts^4 - Ta^4)$$

$$E = K\varepsilon\ (Ts^2 + Ta^2)\ (Ts + Ta)\ (Ts - Ta)$$

$$E \cong K\varepsilon\ 4\ Ta^3\ (Ts - Ta) \qquad (4)$$

To express the measurement error as a change in emissivity, $\Delta\varepsilon$, the detector constant, K, in Equation (1) is chosen so that the detector output, D, is equal to the emissivity, ε, i.e.

$$K = 1/(Td^4 - Ta^4).$$

This expression for K is substituted into Equation (4) along with Equation (3) for Ts - Ta.

$$\Delta\varepsilon \cong \frac{4\varepsilon\ Ta^3}{(Td^4 - Ta^4)}\ \frac{x}{K}\ (150\varepsilon + 120)$$

$$\Delta\varepsilon \cong .856\ \frac{x\varepsilon}{k}\ (1 + 1.25\varepsilon) \qquad (5)$$

For a ¼" thick glass with $k = 0.60$ and $\varepsilon = 0.90$, the error is 0.06. If the glass surface were metallized with $\varepsilon = 0.05$, the error would be 0.0016.

Emissivity Measurements for Materials with Low Thermal Conductivity

This measurement technique for low conductivity materials is based on Equation (5). 'x/k' for the material is determined with the Emissometer, using some 2.5 inch wide tape as a standard.

The actual emissivity of the tape is first measured in the usual manner (see Emissometer instructions), but the tape can be stuck directly to the heat sink with no intervening heat transfer medium. Then a piece of the tape is applied to the surface of the material to be tested and the tape's emissivity is measured again. The decrease in emissivity from the previous measurement is $\Delta\varepsilon$. 'x/k' for the material is calculated from Equation (5). Now to determine the emissivity of the unknown material, measure a sample of the material without the tape in place, and then using the indicated emissivity value, correct as shown below.

$$\varepsilon = \varepsilon\ (\text{ind.}) + \Delta\varepsilon \qquad (6)$$

where, ε (ind.) is the indicated emissivity before correction

$$\Delta\varepsilon = .856\ x/k\ \varepsilon\ (1 + 1.25\varepsilon) \qquad (7)$$

Since the actual emissivity is not known, first calculate the $\Delta\varepsilon$ using the indicated emissivity and use the corrected ε to determine a better value for $\Delta\varepsilon$.

A note of caution: This method assumes that data is taken after thermal equilibrium is established. If the material has a large thermal capacitance, and is slow to reach equilibrium, the transient technique described in the next section might be better.

Example 1. The emissivity of a .3" glass fiber reinforced plastic material was measured, using the method described above. $2\frac{1}{2}$" wide masking tape was used as the standard, $\varepsilon = 0.90$. With the tape on the plastic sample, the emissivity of the tape indicated 0.79, making

$$\Delta\varepsilon = 0.11 = 0.856\ x/k\ (.9)\ (1 + 1.25\ (.9))$$

$$x/k = 0.067$$

Without the tape on the sample, the emissivity indicated $\varepsilon = 0.70$. This value is used as a first guess to find the correction.

$$\Delta\varepsilon = .856\ (.067)\ (.70)\ (1 + 1.25\ (.70)) = .075$$

and the corrected emissivity is 0.78. Now recalculate the correction with $\varepsilon = 0.78$.

$$\Delta\varepsilon = .09$$

and the corrected emissivity is 0.79 . Another iteration repeats the 0.09 correction, therefore the true emissivity is 0.79.

Notice that the constant 0.856 in Equation (5) assumes that the heatsink is at 75F. This does not affect the results since x/k multiplies, and any difference in temperature will be lumped into this term. This constant can be eliminated and a single variable can be used in place of 0.856 x/k. A simpler equation is given here,

$$\Delta\varepsilon = R\varepsilon\ (.8 + \varepsilon) \qquad (8)$$

The constant R will depend not only on the material, thickness, and heatsink temperature, it will also vary from one Emissometer to another, since the temperature of the detector heat sink will vary slightly from unit to unit.

Transient Method for Emissivity Measurements in Place

For many materials it is impractical or impossible to place the sample on the heatsink to make a measurement. If the material is a good thermal conductor, like a metal plate, the sample itself can serve as the heatsink. To determine if the sample conducts well enough to serve as a heatsink, allow the Emissometer to rest on the surface for some time, and then without lifting the detector, slide it over to an identical spot at a distance of about six inches from the original spot. If this spot is cooler, the reading will rise momentarily and then begin to fall back down as the surface under the Emissometer begins to heat up. If the rise in the reading is less than the desired measurement error the heat sinking is adequate.

If this is not the case, a transient method can be applied. Again, a wide masking tape or plastic tape is used as a standard. Put a piece of the tape on the surface at a point at least six inches from the point to be measured. This is to insure that heating of the surface due to the Emissometer does not affect adjacent measuring locations; however, the two spots should be at the same temperature. In addition, for a surface such as a frame wall, the two spots should be similar in terms of heat transfer properties, that is, both should be between studs, or at the studs.

Now if the Emissometer is placed on the tape standard, the detector output will change with time, as indicated in Figure 2. For the first minute, the response of the thermopile affects the detector output. Follow the output response until about 2 to 4 minutes, and then extend the curves back to time zero. This extrapolated reading is about the same as if the surface could be maintained at the original temperature and the detector allowed to come to equilibrium.

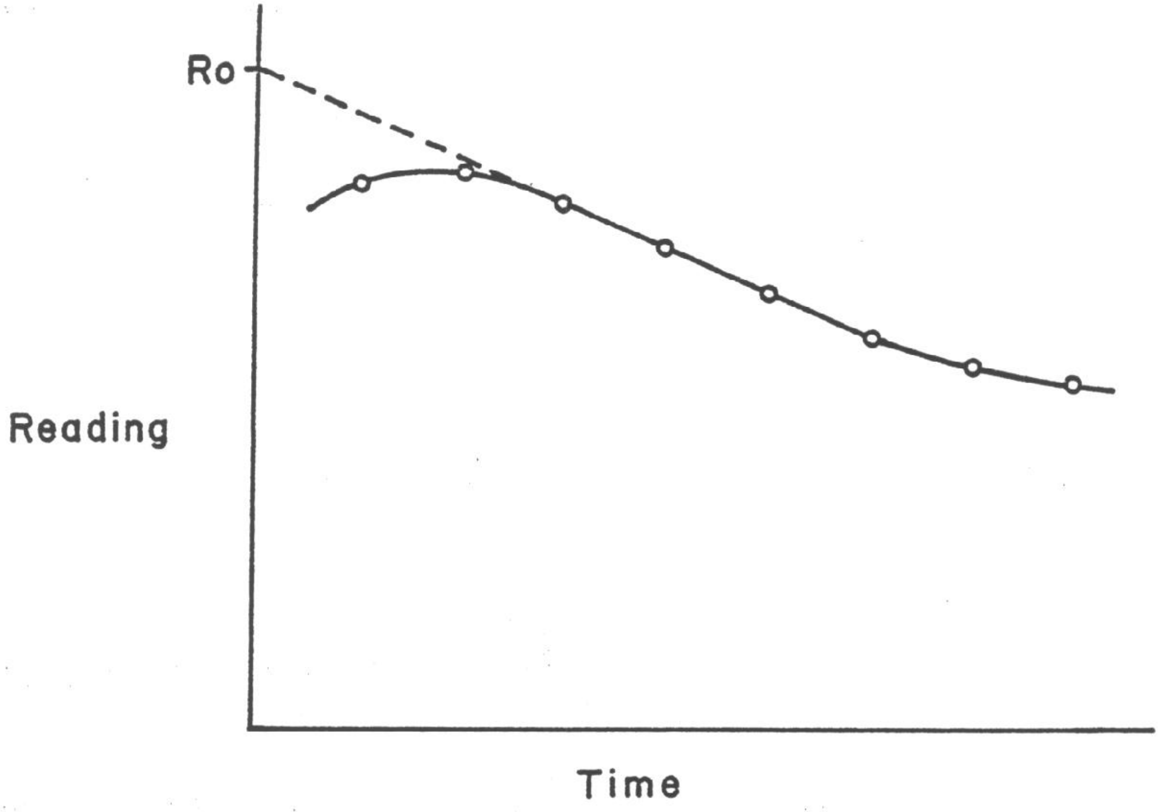

FIGURE 2. Transient Response of Emissometer

The detector reading for the surface is obtained in the same fashion. The emissivity is then calculated from

$$\varepsilon = \frac{\text{Ro for Unknown}}{\text{Ro for Standard}} \times \varepsilon\ (\text{std.})$$

Example 2. The emissivity of formica covered 3/4" particle board was measured using the transient method. The data is given in the table below.

	Voltmeter Reading	
Time (min)	Standard	Board
0	.78	.75
.25	.86	.80
.50	.86	.81
.75	.84	.80
1.00	.82	.79
1.25	.80	.78
1.50	.79	.77
1.75	.77	.77

Extrapolating the near straight line portion of these curves back to time zero,

Ro for the standard = 0.90

Ro for the board = 0.83

and $$\varepsilon = \frac{.83}{.90} \times .90 = 0.83$$