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D&S Technical Note 11-2

Model AE1 Emittance Measurements using a Port Adapter, Model AE-ADP

Introduction

Emittance measurements with the D&S model AE1 Emissometer require that the high and low emittance standards and the sample to be measured be maintained at the same temperature. To achieve a uniform temperature the instrument is provided with a heat sink on which to mount the standards and the sample. For materials that cannot be properly applied to the heat sink, or have low thermal conductivity, it is necessary to correct for the increased surface temperature of the sample when exposed to the heated detector surface.

AE1 detector showing the diffuse black heated substrate and the sensing element (center)

Techniques for making these measurements are described in D&S Technical notes:

TN 79-17 Emissivity Measurements for In-Place Surfaces and for Materials with Low Thermal Conductivity
TN 81-2 Measurement of Emittance of Cylindrical Surfaces
TN 84-2 Emissometer Adapter Model AE-AD1
TN 04-1 Slide Method for AE Measurements
TN 10-2 Slide Method for High Emittance Materials with Low Thermal Conductivity

This note describes the use of a port adapter to make these and other measurements. Standard port adapters are available to measure samples smaller than the 2 1/8 inch diameter of the detector port.

Standard AE-ADP adapter with highly reflective film that redirects radiation heat exchange

For measuring materials with low thermal conductivity, the port adapter has the advantage of reducing the heat load on the sample. The combination of the reduced heat load and smaller port size makes it possible to use the "slide" method described in D&S Technical notes TN04-1 and TN10-2 with a smaller sample area.

The port adapter can also be used for the measurement of cylindrical surfaces without a custom adapter to fit the geometry. The smaller port size reduces errors due to the non-flat surface geometry and due to detector alignment making it possible to manually position the detector. The remaining error due to the cylindrical shape can then be approximately corrected for a range of radiuses and surface emittance values.

A related issue is the measurement of rough or textured flat surfaces, having features significant in size relative to the detector to sample spacing. The presence of surface features causes the sample to be displaced from the port on average. It has been found that the port adapter reduces the error due to sample displacement for high emittance materials. TN 08-1 "Model SSR-ER – Solar Reflectance Measurements of Irregular Surfaces" describes a similar approach to the correction of reflectance measurements.

The use of a port adapter necessarily changes the emittance measurement due to the redirection of reflected energy by the cylindrical section of the adapter, and the reduced port size. Due to the reflections from the adapter, the integration of emittance over angle is modified so that if the emittance standard and the unknown sample have differing angular properties there can be an error introduced. A second source of error can result from reducing the port size. For the AE1 hemispherical emittance measurement the port can be thought of as diffusely illuminated with the reflected energy being collected from the entire area. Because some of the source energy may penetrate the surface by some distance before being reflected back out, there can be some reflected energy that escapes at the edge of the port. The leakage at the edge results in a lower apparent reflectance and thus a higher emittance value. For a smaller port the loss of reflected energy is a larger percentage of the total and therefore an error can occur unless the properties of the standard and the sample are the same. These potential errors are not investigated in detail here; however measurements for different surfaces with and without the port adapter are compared to indicate that significant differences are unlikely for common materials.

Measurement of Materials with Low Thermal Conductivity

The procedure for making measurements with the adapter on materials with low thermal conductivity is detailed below. The basic steps are the same as those for making standard measurements without the adapter. The instrument is first calibrated with high and low emittance standards to establish a straight line relationship between the detector output and the emittance values of the standards. With the port adapter in place it is necessary to adjust the offset using the offset adjustment on the voltmeter (if using the D&S model RD1). Once calibrated the high emittance standard is used to track calibration drift due to small changes in detector temperature and room temperature. The additional step for materials with low thermal conductivity is to move or "slide" the detector sequentially to unheated areas of the sample over a period of about one minute so that the detector transient response plays out over an area of the sample that is near the correct surface temperature. If the material cannot be applied to the heat sink, a preliminary step is needed to assure that the sample and the standards are at the same temperature.

The table below compares emittance values measured with and without the port adapter for various materials including some with low thermal conductivity. These measurements and others reported in this note were made with an RD1 Scaling Digital Voltmeter with the gain increased by 10 times. The reporting of emittance to three decimal places is for comparison purposes and is not indicative of the accuracy or repeatability of the instrument for any particular measurement. The emittance values reported are the average of two or more readings.

Sample	Emittance w/adapter	Emittance w/o adapter
Acrylic coating over Ni plating	0.705	0.704
Acrylic coating over Ni plating	0.458	0.451
Electroless Ni plating	0.142	0.138
Yellow vinyl tape	0.912	0,908
Gray duct tape	0.808	0.792
5/8" Gray plastic	0.902*	0.905*
White ABS	0.916*	0.916*
Press board	0.906*	0.902*

* slide method used to make measurement

These results suggest that for typical materials, using the port adapter is unlikely to result in readings significantly different than making a standard measurement with the model AE1 Emissometer.

Procedure for measuring materials with low thermal conductivity

1. Install the port adapter on the AE1 Emissometer and power it up. Allow about 15 minutes for the detector/adapter combination to warm up to a steady operating temperature. *Note that measurements with the adapter must be made with the detector oriented vertically to prevent errors due to convection.*

2. Calibrate with the high and low emittance standards applied to heat sink with a few drops of water. Adjust the voltmeter gain to set the high emittance value. Important Note – Adjust the *voltmeter offset* (not the detector head offset) to set the low emittance value. There is not enough offset range available on the AE1 detector head to make the adjustment. Some iteration is required.

3. Remove the low emittance standard from the heat sink. For each measurement it may be necessary to make fine gain adjustments on the high emittance standard. The low emittance standard need only be checked occasionally. For high emittance samples, small errors in detector offset are not important.

4. NOTE: If the sample is not flat, too large, or cannot be applied to the heat sink with water see the instructions below. For small flat samples apply the sample to the heat sink with sufficient water to get good thermal contact. Allow a few minutes for the sample to come to thermal equilibrium.

5. Hold the detector/adapter flat against the sample on one corner for about 20 seconds and then “slide” it to an adjacent corner. Move to each subsequent corner after about 15 seconds. Avoid a major break in contact with the surface which will cause an unwanted transient in the detector response. The reading may increase a small amount upon each move due to the lower surface temperature at the new location. The maximum reading obtained on corner number four is the value for this single measurement. To get an average of several readings, start and end at different locations on the sample. Allow a few minutes for the sample to return to an equilibrium temperature and readjust the gain on the high emittance standard between each measurement.

Procedure for measuring materials that cannot be applied to the heat sink

Calibrate the AE1 Emissometer as described above in steps 1 through 3. Continue with step 4 below.

4. For a material that cannot be applied to the heat sink, set the detector aside after calibration and use a small fan to bring the sample and the heat sink, with the high emittance standard applied, to the same temperature. Turn off the fan and then place the detector with adapter on the high emittance standard.

5. Leave the detector on the high emittance standard for two to three minutes until the reading is completely stable and adjust the gain so that the display reads the emittance of the standard.

6. Hold the detector/adapter flat against the sample on one corner for about 20 seconds and then “slide” it to another spot. Move to each subsequent different location after about 15 seconds or more frequently if the sample size is sufficient. Avoid a major break in contact with the surface which will cause an unwanted transient in the detector response. The reading may increase a small amount upon each move due to the lower surface temperature at the new location. The maximum reading obtained at the last location (after about one minute) is the value for this single measurement. To get an average of several readings, start and end at different locations on the sample. Return to step four, cool the sample and heat sink for a few minutes and readjust the gain on the high emittance standard between each measurement.

Measurement of Cylindrical Surfaces

For non-flat surface geometries the measurement is affected by several factors. Since the sample does not fit flat against the port it is necessarily improperly illuminated by source radiation from the heated detector surface. This is similar in effect to the "leakage" at the port edges discussed in the introduction and to the improper illumination of rough or textured surfaces described in a following section. In addition, the differential sensing element must be positioned repeatable relative to the surface to avoid offset errors and errors due to sensor elements viewing the surface asymmetrically. Since the surface does not seal against the port there is also the possibility that air flow will alter the detector reading. In addition, a cylindrical surface typically cannot be applied to the heat sink for measurement and may also be a poor thermal conductor. The "slide" technique may be required to compensate for surface heating.

To control measurement errors a custom adapter is typically created for non-flat surface geometries. The adapter seals against the surface ensuring repeatable alignment and preventing air flow over the detector surface. A custom set of high and low emittance standards is made to match the surface geometry. To determine the emittance values of the standards, film materials such as aluminum and vinyl tape are measured flat and then applied to the non-flat surface. The taped surfaces are used as intermediaries to measure the emittance of the working standards.

For a surface with a large enough radius of curvature and high emittance it is possible to make direct measurements using the port adapter, without requiring a custom adapter and custom emittance standards. Positioning errors are small enough so that an operator can manually align the detector. With the port adapter, corrections for the surface geometry are small for a range of cylindrical radiuses and emittance values. To prevent air flow over the detector surface, a flexible bellows is used to seal against the cylindrical surface.

To establish correction factors for cylindrical surfaces, a number of different model AE1 Emissometers were tested with the model AE-ADP port adapter on four radiuses ranging from 2 to 6 inches. The measurements were made as described below, calibrating the detector/adapter combination on the usual flat emittance standards. Standards matching the cylindrical shape are not required because the correction is small as shown. Two different vinyl tapes were measured applied to anodized aluminum pieces that were machined to the indicated radiuses. The aluminum pieces were attached to a heat sink alongside the emittance standards so that the temperatures were all close to the same.

Gray duct tape:

AE1 #1

Flat	2"	3.33"	4.66"	6"
0.803	0.826	0.817	0.813	0.812

AE1 #2

Flat	2"	3.33"	4.66"	6"
0.801	0.824	0.816	0.810	0.810

AE1 #3

Flat	2"	3.33"	4.66"	6"
0.804	0.823	0.818	0.811	0.810

AE1 #4

Flat	2"	3.33"	4.66"	6"
0.805	0.820	0.814	0.811	0.810

AE1 #5

Flat	2"	3.33"	4.66"	6"
0.802	0.819	0.816	0.812	0.812

AE1 #6

Flat	2"	3.33"	4.66"	6"
0.805	0.825	0.818	0.812	0.811

Yellow vinyl tape

AE1 #1

Flat	2"	3.33"	4.66"	6"
0.913	0.926	0.921	0.916	0.912

AE1 #4

Flat	2"	3.33"	4.66"	6"
0.912	0.919	0.919	0.913	0.912

Note that the difference between the reading on the flat surface and the curved surface is smaller for the higher emittance surface. This would be expected because the loss of reflected energy due the displaced surface is smaller for the high emittance surface since it has a lower reflectance.

Using the average of the measurements of the two vinyl tapes, a correction for measurements using the port adapter was determined. For cylindrical surfaces with a radius of curvature of two inches or greater and an emittance of 0.80 or greater, the following relationship approximately corrects the indicated emittance to the surface emittance of the sample.

e = surface emittance,

e_i = indicated emittance,

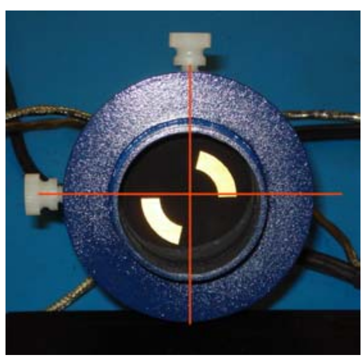
r = radius of curvature in inches,

$$e = e_i - 0.167 * (1-e_i^{2}) / r^{1.32}$$

Note that the corrected emittance value of the cylindrical surface is the surface property of the material as if it were flat. An extended surface with a cylindrical profiled such as a typical roofing tile will always have an effective emittance slightly higher than the surface emittance of the material because there is more actual surface area than projected surface area.

Procedure for cylindrical surface with emittance > 0.80, radius of curvature > 2 inches

To minimize errors due to detector alignment, attach the adapter symmetrically as shown in the photo. The position of the screws will be used to align the detector with the axis of the cylindrical surface which minimizes errors due to slight misalignment.

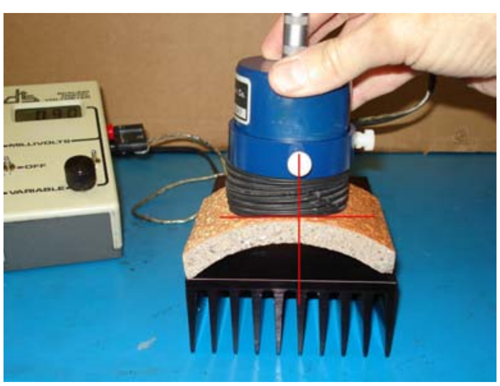


Calibrate the AE1 Emissometer as described in steps 1 through 3 above and continue with step 4.

4. A cylindrical surface cannot be applied effectively to the heat sink, therefore set the detector aside after calibration and use a small fan to bring the sample and the heat sink, with the high emittance standard applied, to the same temperature. Turn off the fan and then place the detector/adapter on the high emittance standard.

5. Leave the detector on the high emittance standard for two to three minutes until the reading is completely stable and adjust the gain so that the display reads the emittance of the standard.

6. Place the bellows on the sample and hold the detector/adapter vertical, square and centered on the cylindrical surface, inside the bellows. Align one of the nylon screws with the axis of the cylindrical surface to ensure that the detector elements view the sample symmetrically. Use the slide technique if the sample size is sufficient. For the sample shown there is only room for two spots with the detector held vertically. It is preferable to have a larger sample. To get an average of several readings, start and end at different locations on the sample. Return to step four, cool the sample and heat sink for a few minutes and readjust the gain on the high emittance standard between each measurement. There is a small correction (maximum of about 0.02) that is required to account for the surface geometry.



Correction factor for a cylindrical surface:

e = surface emittance,

e_i = indicated emittance,

r = radius of curvature in inches,

$$e = e_i - 0.167 * (1-e_i^{\wedge 2}) / r^{\wedge 1.32}$$

Measurement of Rough Surfaces

For a rough or textured flat surface the AE1 Emissometer will be displaced from the surface. The flat circular port may only touch the surface at three points along the perimeter. With the port displaced from the surface there will be a loss of reflected source energy from the heated detector. The effect of surface roughness should be similar to measuring a flat surface that is displaced from the port. The table below shows emittance measurements of flat samples as a function of displacement from the port for the Emissometer with and without the port adapter.

Emissometer with port adapter

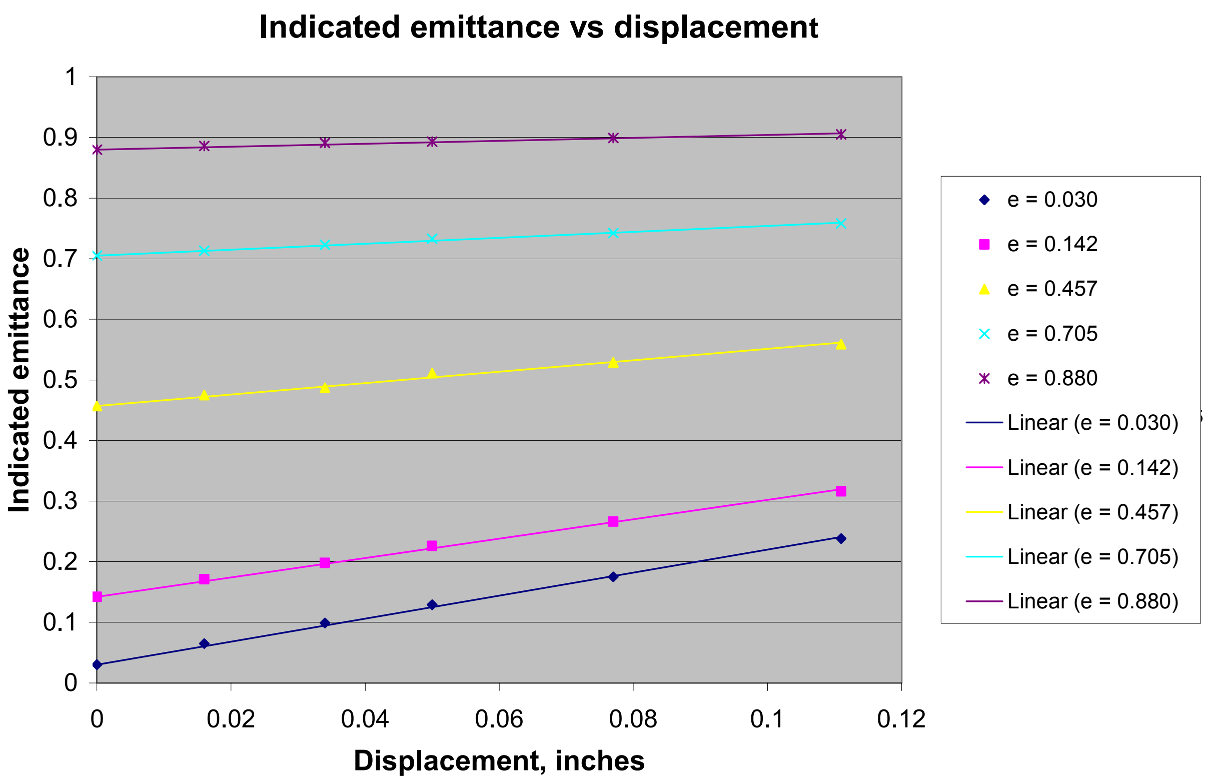
Displacement, inches	e_i	e_i	e_i	e_i	e_i
0.000	0.030	0.142	0.457	0.705	0.880
0.016	0.065	0.171	0.475	0.713	0.886
0.034	0.099	0.198	0.487	0.723	0.891
0.050	0.129	0.226	0.511	0.733	0.893
0.077	0.175	0.266	0.529	0.742	0.899
0.111	0.238	0.316	0.559	0.758	0.905

Emissometer without port adapter

Displacement, inches	e_i	e_i	e_i
0.000	0.030	0.457	0.880
0.037	0.069	0.475	0.923
0.055	0.092	0.487	0.941
0.076	0.127	0.511	0.963
0.116	0.182	0.529	0.983

The behavior of the instrument with the port adapter in place is approximately what would be expected. A rough estimate of the difference in indicated emittance with displacement can be made assuming diffuse surfaces. At a distance of 0.111 inches the diffuse view factor from the port to the gap between the port and the surface is about 15%. The emittance reading should therefore increase on the order of 15% toward 1.00. For the sample with e = 0.88 the reading should be about 0.898 which is close to the actual 0.905 reading. For the sample with e = 0.03, the estimated reading is 0.176 which is comparable to the actual reading of 0.238. For the Emissometer without the adapter the differences are about the same at the low emittance value but much greater for the high emittance sample. The adapter thus offers an advantage when measuring rough surfaces, most of which have high emittance.

The plot below shows the data for the Emissometer measurements with the port adapter:



The variation of indicated emittance with displacement is approximately linear and at a given displacement the relationship between indicated and actual emittance is also nearly linear (actual emittance here meaning the value measured at zero displacement). Comparing different emissometers however there is a little variation. For example at the 0.111 inch displacement, instruments measured the 0.88 emittance sample at between 0.883 and 0.905. Therefore to correct for displacement a linear approximation is recommended based on emittance measurements of the working standards at a chosen nominal maximum displacement for the particular instrument and adapter. The equations are given below:

e_L = emittance of the low e working standard
e_H = emittance of the high e working standard
D = chosen nominal maximum displacement
e_{LD} = indicated emittance of low e standard measured at the chosen displacement
e_{HD} = indicated emittance of the high e standard measured at the chosen displacement
R_s = indicated emittance of the unknown sample
e_s = corrected emittance of the unknown sample
d = average surface displacement of the unknown sample

$$E_L = e_L + (e_{LD} - e_L) * d / D$$
$$E_H = e_H + (e_{HD} - e_H) * d / D$$

$$e_s = (e_H - e_L) * ((R_s - E_L) / (E_H - E_L)) + e_L$$

Using a maximum displacement of D = 0.111 inches, e_H = 0.88, e_{HD} = 0.905, e_L = 0.03 and e_{LD} = 0.238, the corrected emittance values for the data in the table above are as follows:

Corrected emittance w/port adapter

Displacement, inches	e_i	e_i	e_i	e_i	e_i
0.000	0.030	0.142	0.457	0.705	0.880
0.016	0.035	0.145	0.458	0.704	0.882
0.034	0.036	0.142	0.451	0.704	0.884
0.050	0.031	0.143	0.459	0.705	0.882
0.077	0.031	0.138	0.447	0.697	0.882
0.111	0.030	0.129	0.439	0.693	0.880

The corrections will be more accurate if it is not required to measure samples over the entire range of emittance values. For example the “low emittance standard” could be a sample prepared to have a higher emittance instead of 0.03 as in this example. If the correction is applied between emittance values of 0.457 and 0.880, the following corrected emittance values are obtained.

Corrected emittance w/port adapter over the range 0.457 to 0.880

Displacement, inches	e_i	e_i	e_i	e_i
0.000	0.142	0.457	0.705	0.880
0.016	0.148	0.460	0.705	0.882
0.034	0.150	0.456	0.706	0.884
0.050	0.155	0.466	0.708	0.882
0.077	0.157	0.458	0.702	0.882
0.111	0.160	0.457	0.700	0.880

To use this method to correct for surface roughness it is necessary to estimate the average displacement of the sample from the port. The port adapter can be employed for this purpose by using a caliper to measure from the shoulder of the adapter down to the surface. Take care not to damage the reflective film applied to the inside surface of the adapter. By measuring random points on the surface and subtracting out the height of the adapter to the shoulder, the average displacement of the surface can be determined.

As opposed to the measurement described for a cylindrical surface the emittance measurement here includes the effect of the surface "geometry" on the emittance value. As the scale of surface features increases beyond about one tenth of an inch or so, the surface will begin to appear to the detector port as a non-flat surface geometry rather than a rough flat surface.