Devices & Services Co.

D&S Technical Note 84-2

EMISSOMETER ADAPTER Model AE-AD1

Introduction

An adapter has been developed that enables the Emissometer to be used to measure the emittance of solar absorber panels that have tubes running the length of the front surface where the distance between the tubes is less than the 2 1/4 inch diameter of the Emissometer. It will adapt the Emissometer to any surface that has a flat area of 1 1/2 inches in diameter. The adapter will clear an obstruction on the surface, up to 3/8 inch high. Two plastic screws hold the adapter in place over the detector end of the Emissometer. From a collar that fits around the Emissometer, the adapter steps down to a 1/2 inch long by 1 1/2 inch diameter tube, at the end of which is the sample port. The interior of the tube is covered with a highly reflective and specular material. This surface redirects both the thermal radiation emitted by the detector and that emitted by the sample, such that the detector voltage output remains high even though the sample is at a greater distance from the detector.

With the adapter in place, the Emissometer can be used in the normal manner to make emittance measurements on the above mentioned types of surfaces. That is, it is calibrated on high and low emittance standards (just as it is without the adapter in place) and then the emittance of the material can be read directly by placing the Emissometer with adapter on that material. The adapter can be used as is for horizontal surfaces. Because of the increased air space with the adapter in place, free convection causes measurement errors on inclined surfaces. For inclined surfaces that cannot be positioned horizontally, a plastic film can be installed over the face of the detector to reduce the effects of convection and make the measurement feasible.

Theory of operation:

For the usual emittance measurement, the Emissometer is placed over a flat sample as shown in Figure 1.

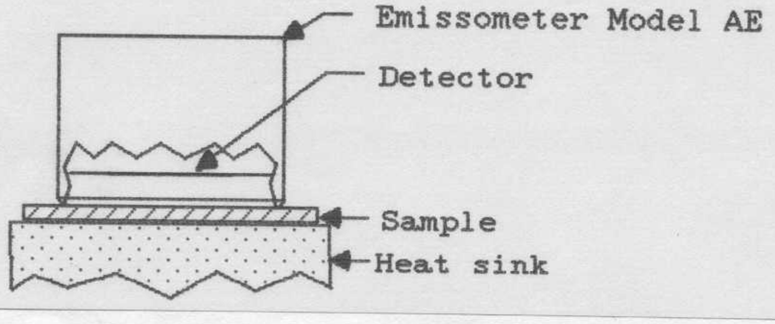

Figure 1. Emissometer Measurement Configuration

A heater maintains the temperature of the detector mount and the radiation sensing element at 180F. The sample is held at room temperature. Due to the temperature difference between the surface of the sample and the detector there will be heat transfer by conduction, convection and radiation. The sensing element in the Emissometer is a differential thermopile, measuring the temperature difference between low and high emittance areas on the sensing surface. Ideally the heat transfer by conduction and convection is the same for both the low and high emittance areas, and therefore the detector output will depend only on the radiation heat transfer.

Figure 1 shows how the sample and detector form a parallel plate geometry. The energy incident at the detector surface consists of thermal radiation emitted by the sample and that emitted by the detector surface that is reflected by the sample back to the detector. Although the details of the radiation exchange are complicated, the difference in heat loss between the low and high emittance areas is approximately a linear function of the emittance of the sample. See D&S Technical Note 79-19 for a detailed explanation.

Figure 2 shows the Emissometer with the adapter in place. The side walls on the adapter are covered with a highly reflective and specular material. If this material were perfectly specular and perfectly reflective, the configuration shown in the figure would be, for the purpose of radiation heat transfer, essentially identical to having the sample at the normal position. Of course the sample area is reduced to the smaller diameter of the adapter tube. In theory it wouldn't matter how long the cylindrical portion of the adapter were, and therefore, the spacing should not make a difference in the magnitude of the output. However, because the sample size is reduced and because the reflective material is not perfectly reflective, some change in the detector response should be expected.

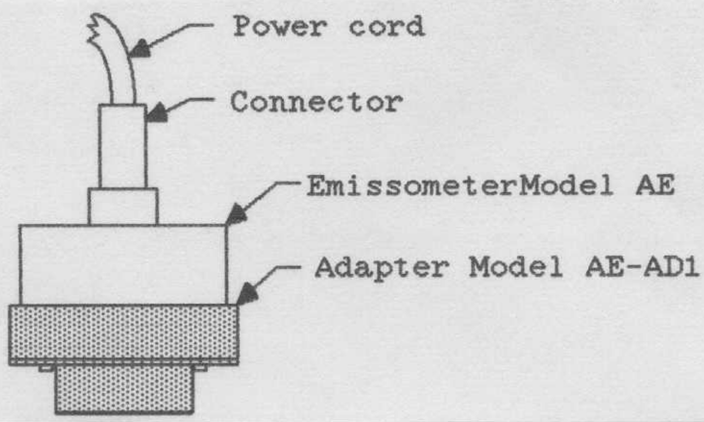

Figure 2 Emissometer with AE-AD1 adapter

Adapter Performance Testing: I. Adapter Temperature

As originally proposed, there was no means by which the temperature of the adapter would be controlled at a set or constant temperature. For the usual emittance measurement, the temperature of the sample determines the magnitude of the voltage output from the detector. As the sample temperature increases the output decreases. Since the detector views portions of the adapter as well as the sample when installed, it was assumed that the temperature might need to be controlled in order to prevent drift in the detector output.

For this reason a test was devised to determine the possible effect of drift by artificially changing the temperature. The Emissometer with the adapter in place was allowed to come to thermal equilibrium while resting on a sample with an emittance of about 0.90. The sample was maintained at near room temperature using the heat sink provided with the Emissometer. At thermal equilibrium, each portion of the adapter stabilizes at some point between the 180 F detector temperature and room temperature. The voltage output of the Emissometer was recorded at equilibrium conditions and then the adapter temperature was lowered to near room temperature by cooling with a small fan. The detector output showed a change equivalent to less than 0.01 emittance units. The change in the adapter temperature for this test is much greater than would be expected in normal operation. This testing and the stability of the readings in the other testing described in this note indicate that the temperature of the reflective side walls and the area of the adapter outside the sample area cause insignificant changes in the voltage output of the detector. This is a very convenient result in that it becomes unnecessary to control the temperature of the adapter.

II. Accuracy of Measurements with the Adapter

The initial testing was followed by comparison measurements of emittance with and without the adapter in place for a range of samples. The samples were measured in the normal manner on the heat sink supplied with the Emissometer. The measurements are summarized in Table 1. A Model RD1 voltmeter was modified for these measurements, to increase the resolution beyond the usual two decimal places. The measurements without the adapter were obtained in the normal manner following the instructions for the Emissometer. For those measurements with the adapter, a special technique was required to calibrate the device. The presence of the adapter causes a much larger offset in the voltage output of the detector. Due to the large offset it is necessary to use the offset adjustment on the voltmeter instead of the offset adjustment on the Emissometer detector. The Emissometer offset adjustment does not have enough range. This calibration procedure was used throughout the testing of the adapter.

The Emissometer with the adapter was first placed on a high emittance standard, and the voltmeter scaling knob was used to adjust the reading to the value of the standard. The Emissometer with adapter was then placed on the low emittance standard and the zero offset adjustment of the voltmeter was used to adjust the reading until the emittance of the low standard was achieved. This procedure was repeated until the Emissometer with adapter would read correctly for both low emittance and high emittance standards with no adjustments.

The agreement between the measurements with and without the adapter in place are within the limits of error for the Emissometer itself. Some error would however be expected because of the change in the geometric configuration of the sample and the detector, and the less than perfect reflection of the sidewalls of the adapter.

SAMPLE	Emittance Measurement without adapter	Emittance Measurement with adapter
Glass	0.872	0.874
Metallized Film	0.798	0.800
Copper Paint	0.362	0.367
Stainless Steel	0.196	0.201
Aluminum Foil	0.031	0.034

Table 1. Comparison of Emittance Measurements With and Without the AE-AD1 adapter

Further tests were devised to determine how the Emissometer with adapter would respond at sample inclination angles other than horizontal. Without the adapter the response is largely independent of inclination angle. However, with the adapter in place, there is a larger air space and it was anticipated that there might be a greater dependence on inclination angle. It was also found that the output is dependent on the azimuth angle relative to the low and high emittance sectors. Therefore, the test involved calibrating the Emissometer at horizontal, and then determining detector outputs at various inclination and azimuth angles. Figure 3 shows how the inclination angle and azimuth angle were defined for the test. The data is summarized in Table 2. One of the low emittance standards was used for this test. The changes in emittance will be similar for a material with a different value of emittance because the errors are due to changes in offset rather than gain.

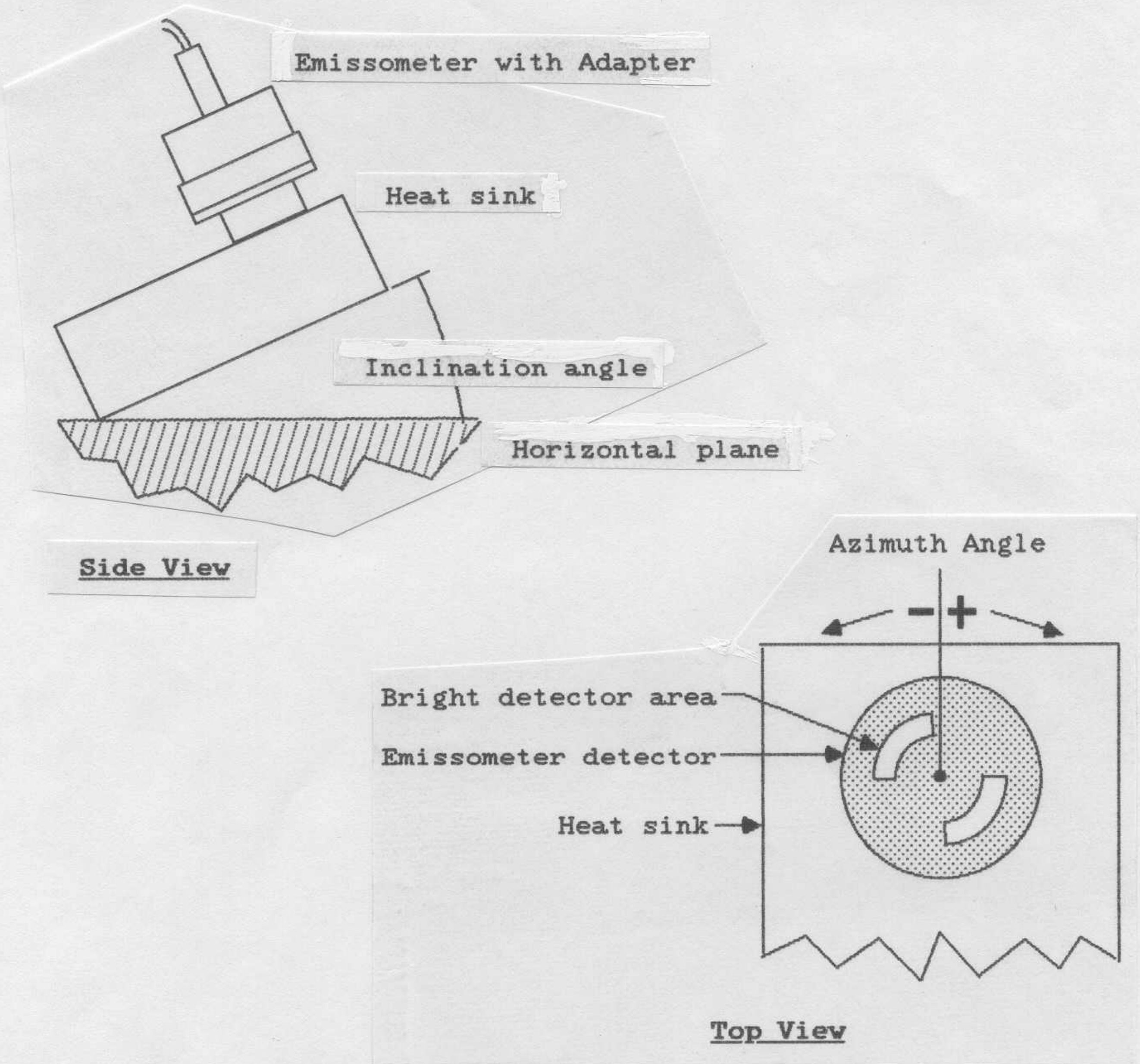

Figure 3. Illustration of Inclination and Azimuth Angles

Azimuth Angle	Inclination Angle: Horizontal	5 degrees	11 degrees	30 degrees	60 degrees
+45		0.127	0.151	0.227	0.241
+30		0.127	0.148	0.215	0.229
+20		0.126	0.142	0.194	0.200
+15		0.125	0.140	0.176	0.182
+10		0.125	0.136	0.157	0.169
+5		0.124	0.135	0.147	0.155
0	0.124	0.124	0.130	0.129	0.141
-5		0.123	0.124	0.112	0.112
-10		0.123	0.122	0.093	0.098
-15		0.122	0.118	0.081	0.079
-20		0.121	0.115	0.067	0.058
-30		0.119	0.107	0.041	0.029
-45		0.119	0.100	0.019	0.002

Table 2. Emittance vs. Inclination and Azimuth angles for the AE with adapter

At near zero azimuth angle, the output remains relatively constant with angle of inclination. This is apparently due to the fact that the convection pattern is symmetric, affecting both the high and low emittance areas of the Emissometer detector the same way and therefore the effect cancels out. However, even at very moderate angles of inclination, the variation with azimuth angle is quite abrupt. Therefore, calibrating the Emissometer on a horizontal surface or even on an incline and then measuring a sample at the same angle would be highly inaccurate due to the large change in output with azimuth angle.

This problem suggested the use of a thin film that is transparent to infrared radiation, over the opening in the adapter to eliminate the effects of convection due to the presence of the adapter. To test the idea, a polyethylene film was stretched over the face of the Emissometer and then the adapter was attached, holding the film in place. Figure 4 shows the location of the transparent film. The infrared properties of the film were measured with the Emissometer and were determined to be as follows: transmittance was 79% and emittance of was 13%. The technique for measuring these properties is described in Devices and Services Co. Technical Note TN 80-1.

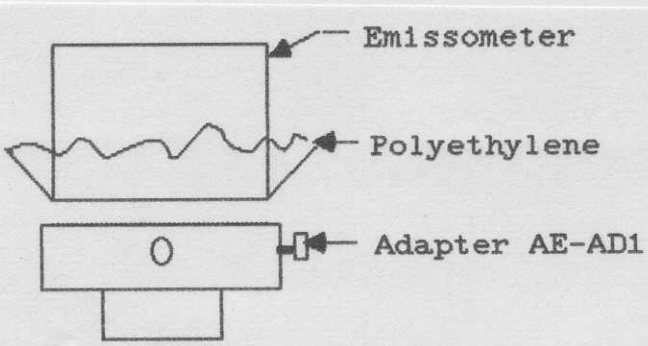

Figure 4. Position of Film installed with adapter

The inclination tests were repeated with the polyethylene film in place. The data from the test is summarized in Table 3. The presence of the film very greatly reduces the effect of azimuth angle but there still remains some effect of sample inclination, and the variation is large enough that the error should not be ignored. Therefore, for measurement of inclined materials, it is necessary to calibrate the unit at the same angle or determine a correction factor for the different angles of inclination.

	Inclination Angle		
Azimuth Angle	Horizontal	30 degrees	60 degrees
+45	0.119	0.138	0.144
+30	0.120	0.136	0.145
+15	0.119	0.134	0.145
0	0.120	0.131	0.143
-15	0.119	0.130	0.143
-30	0.119	0.127	0.142
-45	0.119	0.124	0.139

Table 3. Emittance vs. Inclination and Azimuth angles with adapter and film

The comparison test for the materials listed in Table 1 was repeated with the film installed. The tests were done at horizontal and the results are presented in Table 4.

SAMPLE	Emittance Measurement without adapter	Emittance Measurement with adapter
Glass	0.872	0.884
Metallized Film	0.798	0.791
Copper Paint	0.362	0.374
Stainless Steel	0.196	0.198
Aluminum Foil	0.031	0.032

Table 4. Comparison of Emittance Measurements With AE-AD1 adapter and film

III Sample Temperature Dependence

Due to the fact that in many cases the samples to be measured cannot be placed on the heat sink that is supplied with the Emissometer, and cannot be maintained at a controlled temperature, it is important to know how the Emissometer responds with variations in sample temperature. Test data for the Emissometer without the adapter is given in Table 5 for sample temperatures ranging from 70 to 120F. The Emissometer was calibrated at 72 F and neither the offset nor gain adjustments were changed as the sample temperature was raised up to 120F. The coefficients A & B in the table relate the voltage output to the actual emittance. That is, the emittance is equal to A times the the output as given in the table, plus B.

$$e = A \text{ (Reading)} + B$$

Sample Temperature	Reading on Low standard	Reading on High standard	(Gain) A	(offset) B
72 F	0.030	0.90	1.00	0.00
79	0.035	0.872	1.039	-0.006
91	0.032	0.817	1.108	-0.005
102	0.029	0.775	1.166	-0.004
110	0.017	0.734	1.213	0.009
120	0.017	0.671	1.330	0.007

Table 5. Variation of output with sample temperature for the Emissometer

The constant A is the relative gain and B represents an offset in units of emittance. The data for the Emissometer without the adapter in place show that the offset changes by a very small amount, but the gain changes significantly. This is because of the way the Emissometer is designed to cancel out the effects of conduction and convection. The output is primarily a function of the sample emittance alone. However, the change in gain is due to the fact that the radiation heat transfer is dependent on the difference in temperature between the detector and the sample. This temperature difference is greatly reduced at the higher sample temperatures. The change in the B coefficient represents the amount of adjustment that would have to be made in the offset to make the Emissometer read the correct emittance units at the higher sample temperature and the change in the A coefficient represents the amount of increase in the gain that would be required. Because of the stability of the offset with temperature, the sample temperature will not be extremely critical for the measurement of low emittance materials. For example, using the data in Table 5, and assuming that the Emissometer was calibrated at 72 F, the following emittance values would be obtained if the sample temperature was other than 72 F.

Sample Emittance (Tcal = 72F)	Measured Emittance (Tsample = 91F)	Measured Emittance (Tsample = 110F)
0.030	0.032	0.017
0.100	0.095	0.075
0.200	0.185	0.157
0.500	0.456	0.404
0.900	0.817	0.734

Table 6. Measure Errors vs Sample Temperature for the Emissometer

Similar data has been taken for the Emissometer with the adapter in place and with the adapter and the transparent film in place.

Sample Temperature	Reading on Low standard	Reading on High standard	(Gain) A	(Offset) B
72 F	0.146	1.142	0.873	-0.098
80	0.139	1.073	0.931	-0.099
94	0.139	0.993	1.019	-0.112
107	0.135	0.900	1.137	-0.124
120	0.131	0.826	1.252	-0.134

Table 7. Variation of output with sample temperature for the Emissometer with adapter

Sample Temperature	Reading on Low standard	Reading on High standard	(Gain) A	(Offset) B
76 F	0.235	0.967	1.189	-0.249
93	0.224	0.849	1.392	-0.282
106	0.211	0.780	1.529	-0.293
120	0.206	0.704	1.747	-0.330

Table 8. Variation of output with sample temperature for the Emissometer with adapter and film

No adjustment was made to either the voltmeter gain or the offset on the Emissometer for these measurements. Notice that there is a sizeable offset introduced by the adapter and even a larger offset by having the adapter and the film in place. Also, notice that the offset changes much more with temperature than it did without the adapter in place. For this reason, the sample temperature will be more critical even for low emittance materials.

For example, assuming again that the detector is calibrated at room temperature and the sample temperature is in error, the data below, taken from Tables 7 and 8 illustrate the expected errors in the emittance measurements.

Sample Emittance (Tcal = 72F)	Measured Emittance (Tsample = 94F)	Measured Emittance (Tsample = 107F)
0.030	0.023	0.019
0.100	0.083	0.073
0.200	0.169	0.149
0.500	0.426	0.380
0.900	0.768	0.687

Table 9. Measurement Errors vs Sample Temperature for the Emissometer with adapter

Sample Emittance (Tcal = 76F)	Measured Emittance (Tsample = 93F)	Measured Emittance (Tsample = 106F)
0.030	0.019	0.006
0.100	0.079	0.060
0.200	0.164	0.138
0.500	0.420	0.371
0.900	0.762	0.683

Table 10. Measurement Errors vs Sample Temperature for the Emissometer with adapter and film

Conclusions and recommendations:

1. The adapter as described in this technical note can be used with the Emissometer Model AE to make measurements on horizontal materials with flat areas as small as 1.5 inches in diameter. It will accommodate materials with tubes or other obstructions that would not allow the samples to be measured with the Emissometer alone. The measurement error can be expected to be very nearly the same as the error limits specified for the Emissometer alone.

2. For measuring surfaces at inclination angles greater than about 5 degrees, it is recommended that a transparent film, that will be supplied with the adapter, be installed over the front of the Emissometer detector to prevent errors due to convection. Even with the film in place there is still a calibration error that will occur at different angles and should be accounted for by either calibrating at the angle at which the measurement is going to be made or generating a correction for different angles.

3. Using the Emissometer adapter, the temperature of the sample becomes more critical. For low emittance materials ($e < 0.20$) the error with the Emissometer alone is usually tolerable for a sample temperature within 10F of the standard, however, with the adapter in place the sample temperature becomes more critical and therefore should be monitored more carefully.

4. Based on these results it should be possible to produce a similar adapter for any number of different surface geometries, including tubes and other regular surfaces. This could be accomplished by machining the cylindrical portion of the adapter to fit the particular surface.