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A LOW COST, PORTABLE INSTRUMENT FOR MEASURING EMITTANCE

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ABSTRACT

A low cost, portable instrument has been developed with which emittance can be measured by comparison to a standard. A reflector collects infra-red radiation from a heated sample onto a low mass, black detector and the temperature rise of the black detector is measured with a thermocouple and meter. Graphical examples are presented for determination of emittance from measurements made on a sample at any known temperature.

INTRODUCTION

In support of the national solar energy program NASA-Lewis Research Center has conducted research on methods of formation of radiation selective coatings for solar collectors (ref. 1). To be effective such coatings must absorb strongly in the solar spectrum (<2 microns) but emit very weakly in the infra-red (>2 microns). In order to expedite the development of optimum coatings with high absorptance (α) and low reradiative emittance (ε), simple devices are desirable for measuring α and ε. Generally emittance has been measured by complex and costly instruments such as integrating reflectometers, diffuse reflectance infra-red spectrophotometers, or calorimeters. Some costly direct reading devices have also been developed (ref. 2). Laboratory coating development, process line production control and field installation of solar collectors all would benefit from the development of a low cost, portable instrument which has the capability of rapidly measuring emittance. This paper describes such an instrument, its construction, and method of measurement.

APPARATUS

The principle of this instrument involves measurement of the infra-red energy radiated from a sample at a known temperature and calculation of emittance by comparison with the measurement of energy radiated from standard samples of known emittance.

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The infra-red radiant energy was measured by placing a reflector on the sample to be measured. Positioned at the focal point was a low mass, thin foil detector with an attached thermocouple. This detector was highly absorbing in the infra-red. The resulting apparatus is shown schematically in figure 1 and a photograph of the instrument is shown in figure 2. Infra-red radiation from the sample is thus focused on the foil detector and increases its temperature until it reaches radiative equilibrium with the sample. The temperature of the foil is measured with the thermocouple and an appropriate meter.

In this investigation the reflector used was a flashlight type, aluminized, parabolic reflector approximately 5 cm in diameter. The detector was 0.0025 cm thick brass foil. A 0.0125 cm diameter chromel-alumel thermocouple was soldered (with minimum solder) to the center of the brass sheet. The detector foil was painted with a highly absorbing black paint. The detector foil was positioned at the focal point of the parabolic reflector, parallel to the axis of the parabola, by cementing the thermocouple wires to the reflector where they were brought out thru the opening in the back (where the flashlight bulb is normally inserted. This opening was then filled with silicone rubber. This suspension by the thermocouple wires had the advantage that the thin foil detector did not make contact with the reflector, thus minimizing conductive losses.

The exact size of the foil and parabolic reflector are not critical. Increased foil size increases the collected infra-red radiation but also increases reradiation to the sample being measured. In general the lower the mass of the foil and attached thermocouple junction, the faster the foil will reach thermal equilibrium and the more rapidly measurements can be made. A reflector of larger diameter would increase the collected infra-red radiation but would also give a measurement which is integrated over a larger area, and, if too large, could exceed the sample size. Additionally, a small reflector is more convenient to use and transport.

DESCRIPTION OF MEASUREMENTS

When the reflector and contained detector are initially placed on the indirectly heated sample of unknown emittance, that had been thermocoupled for temperature measurements, the infra-red radiation incident on the detector increases the temperature of the foil at a rapid rate. One method of heating the sample which was used was placement of the sample on a copper block resting on a hot plate. The sample can also be heated with steam or in actual hardware, by incident solar energy. As the foil approaches radiative equilibrium with the sample, its temperature rises more slowly and asymptotically approaches an equilibrium value. Both the rate of temperature increase and the equilibrium temperature reached are determined by the emittance of the surface as well as the temperature of the surface. Figure 3 shows the increase in foil thermocouple output (meter reading) as function of time for three secondary emittance standards of $\varepsilon = 0.13$, 0.53, and 0.95, all measured at a temperature of 100 °C. The rate of increase of temperature and the final equilibrium temperature of the detector foil are, of course, higher for samples having higher emittance. All measurements used in subsequent studies were taken at 30 seconds contact time, approximately the meter reading obtained at equilibrium.

The emittance of the secondary standards (approximately 10 cm x 15 cm) was determined by both calculation from the total, diffuse, hemispherical infra-red reflectance as measured on a Willey 318 Michelson interferometer type of spectrophotometer and also by measurement of the emittance with a calorimeter. Using the above standards for calibration of the instrument, the emittance of an unknown sample may then be established by interpolation after measurement of the unknown sample on the instrument at the same temperature.

In the case that the unknown sample is of considerable bulk--such as solar collector in a field installation--and it is not convenient to adjust it to the temperature at which the standards were most conveniently measured, then the standards may be placed on the surface of the unknown until they come into thermal equilibrium with the unknown. Then both the unknown and the standards can be measured in place at that temperature and the emittance of the unknown interpolated from these measurements. Whenever using the procedure described above it is not necessary to know the temperature of the unknown sample.

In order to simplify the use of the instrument for measurement of emittance of unknown samples for which the temperature can be measured, the various meter readings of the standard emittance samples can be determined for temperatures from ambient to approximately 160 °C. This technique obviates the repeated, continued use of standards and minimizes the risk of damaging the standards. A design change of thermocouple or ammeter could permit measurements to somewhat higher temperatures. The results of such measurements at temperatures from ambient up to 160 °C are shown in figure 4. From data of the type shown in figure 4 a re-plot can be made of meter reading versus emittance fraction for various temperatures from 60 to 160 °C as shown in figure 5. From such a correlation the emittance of any solar selective coated sample can be determined by using the temperature of the unknown sample and the meter reading.

DISCUSSION

The instrument is based on the principle of thermal equilibrium between the detector foil and the sample being measured. The detector foil is heated by radiation, conduction, and convection Conductive heating is made small by supporting the detector foil by only very thin thermocouple wires. Convective heating of the foil is more significant. Some convective heating is present as evidenced by the non-convergence at zero of the lines in figure 5. However the instrument is used in a comparative manner and compares the signal received from an unknown sample to the signal produced by a sample of known emittance. Thus the convective heating of the detector, and also the conductive heating, is constant for both the unknown and the standard. Convective heating could be reduced by placing a thin plastic film across the open face of the reflector. However this would decrease the signal intensity due to the absorption of the infrared radiation by the plastic film. This would then lower the sensitivity of the instrument significantly.

Measurement of the signal from the detector could be made with a microammeter, hand potentiometer, or with a recording potentiometer. Availability, sensitivity, cost, and portability are the factors to be considered in the selection of such a meter. An instrument where the readings occur at the higher part of the scale range would also be more desirable.

Using this instrument the integrated emittance of a sample can be determined rapidly. Typical measurements require 0.5 minutes each. Several minutes are required for normal cool down of the detector to ambient.

The instrument described above is a comparative device which permits calculation of emittance from comparative measurements of radiant energy, from, first, a sample of known emittance and, then, from a sample of unknown emittance. Thus the accuracy of measurements made with this instrument are fundamentally dependent on the accuracy with which the emittance of the standards are known. In order to determine the accuracy of measurements which could be obtained with the instrument two of the secondary emittance standards were measured at least eleven times. The emittance of each standard was known with an accuracy of ±0.005 emittance units. The results are presented in table 1. Comparison of measurements obtained for the standards of emittance indicate that the accuracy of the instrument can be conservatively estimated to be ±0.05 emittance units.

The comparative values for the approximate time required for measurement, accuracy, approximate cost of instrument for both this instrument and for other instruments used for measuring emittance are given in table 2. While this device has a somewhat lower accuracy than the other methods of emittance measurement, it is fast (once it is calibrated), it is very low in cost, and is the most portable of all equipment shown in table 2.

SUMMARY OF RESULTS

A simple, inexpensive device has been designed and constructed with which the emittance of solar selective coated materials can be measured by comparison with standards of emittance. Using this device emittance can be measured to approximately ±0.05 emittance units.

ACKNOWLEDGEMENTS

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REFERENCES

1. G. McDonald, and H. B. Curtis, Optimized Selective Coatings for Solar Collectors, NASA TM X-73498 (1976).
2. R. E. Gaumer, G. F. Hohnstreiter, and G. F. Vanderschmidt, in Measurement of Thermal Radiation Properties of Solids. NASA SP-31 (1963), pp. 117-126.

TABLE I. - MEASUREMENT OF EMITTANCE WITH THE LOW COST INSTRUMENT

Emittance of standards[a] (secondary), emittance units	Average emittance measured with low cost instrument emittance units	Standard aviation, σ, emittance units
0.060±0.005	[b]0.066 (11)	0.008
.065±0.005	[b] .965 (12)	.011

[a] Measured spectroscopically and related to NBS standards

[b] Number of measurements made

TABLE II. - COMPARISON OF EMITTANCE MEASURING DEVICES

Method of measurement	Approximate time required for measurement	Accuracy, emittance units	Approximate cost of device	Portability
Low cost instrument (this study)	0.5 min	0.05	[a]$500	Yes
Integrating reflectometer	2 min	0.03	$10,000	Yes
Infra-red diffuser reflectance spectophotometer	20 min	0.005	$50,000	No
Calorimeter	1 day	0.002	$2,000	No

[a] For a home constructed instrument, approximately $10-$100, depending on the cost of thermocouple and meter.

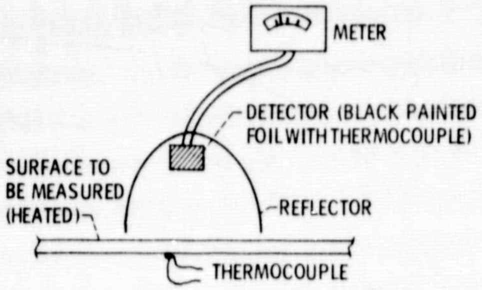

Figure 1. - Low cost emittance measuring instrument - schematic

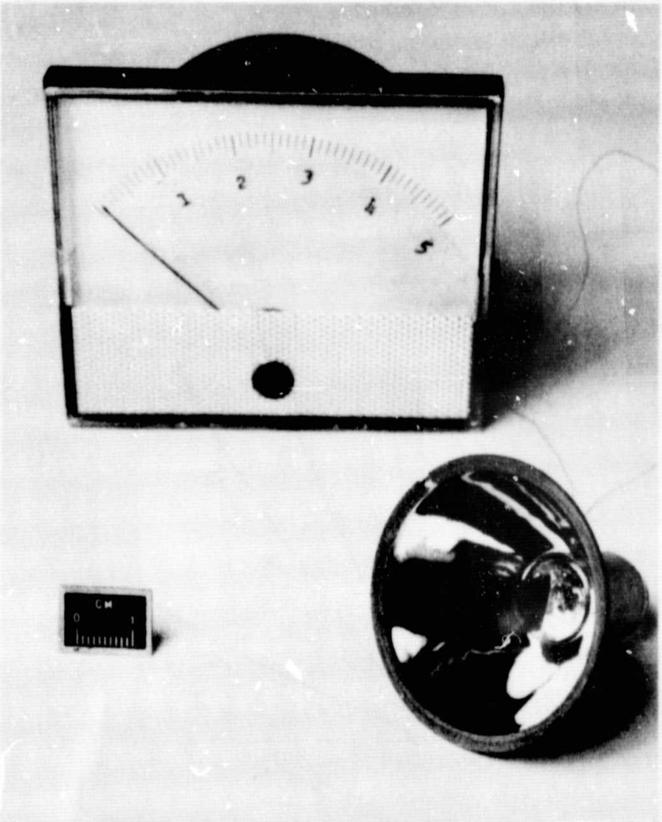

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Figure 2. - Low cost emittance measuring instrument; ammeter, upper center; parabolic reflector, lower right.

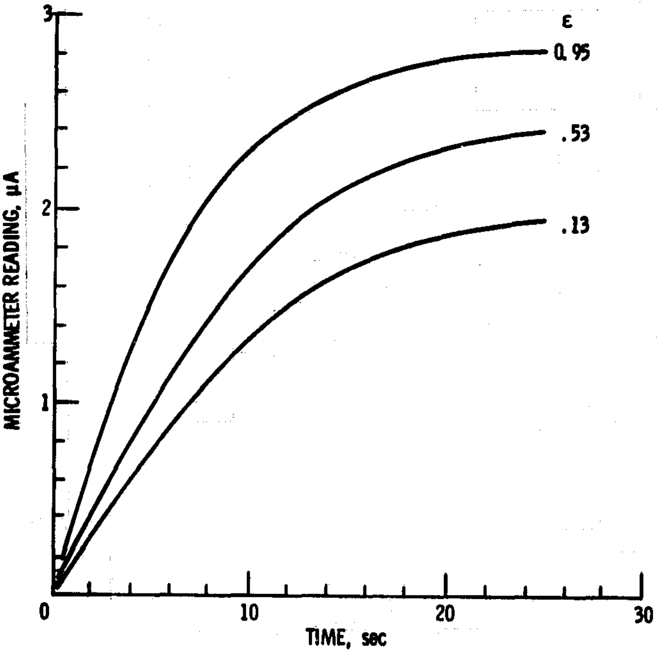

Figure 3. - Microammeter reading vs time for various standard emittances at 100° C.

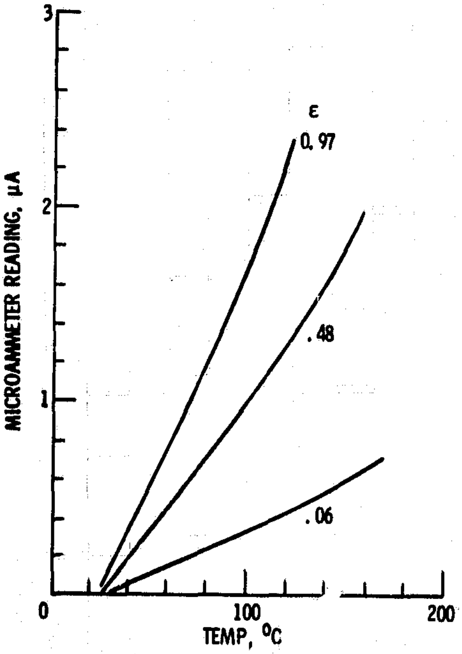

Figure 4. - Microammeter reading vs temperature for various secondary emittance standards

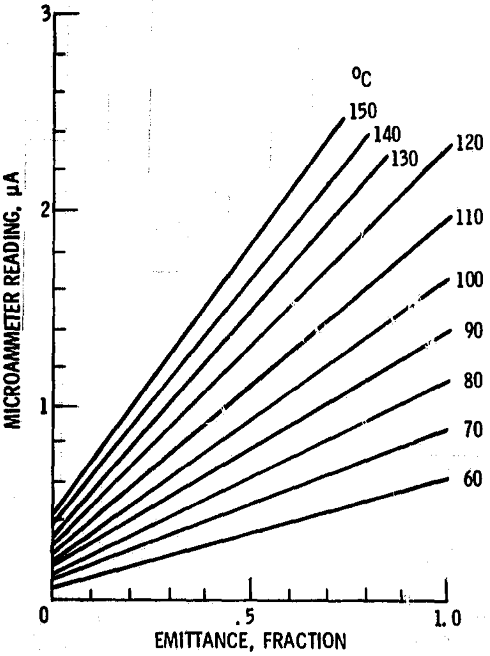

Figure 5. - Replot of microammeter reading vs emittance at various temperature.