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THERMAL-OPTICAL PROPERTIES OF FLUOREL L-3203-6 AND 1059

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SUMMARY

Fluorel[1] and four Fluorel derivatives were irradiated with electromagnetic energy to determine their reflectance, transmittance, absorptance, and emittance. The total-directional and spectral-hemispherical properties, required for engineering analysis, were calculated using Johnson (solar) and Planck (infrared) distributions, and the resulting data were tabulated for convenient engineering use. Evaluation of the data indicates that Fluorel, which is a dielectric material, effectively absorbs energy in the solar- and infrared-wavelength range; therefore, Fluorel is an effective heat sink. The study also showed that the thermal-optical properties of Fluorel vary with fabrication technique, material application, and thermal environment. Consequently, the data presented in this report must be considered representative engineering data. An accurate thermal analysis will require that the thermal-optical properties of the specific hardware be measured and that the thermal environments be known to calculate the absorptance-to-emittance ratio used for analysis.

Finally, methods developed in statistical thermodynamics were used to calculate mean values for the measured spectral and angular data and for two specific energy distributions. These mean values are the thermal-optical properties that are required for thermal analysis.

INTRODUCTION

Recently developed Fluorel compounds, which are nonflammable in spacecraft environments, have been developed, and equipment has been fabricated from Fluorel to replace more flammable spacecraft materials. When Fluorel cannot be used to replace combustibles because of structural, electrical, or other properties, the combustible materials frequently are encased in Fluorel to prevent the ignition of the combustible material. Because Fluorel is a spacecraft material that will be used in various

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[1] Fluorel is a trade name given to a series of compounds made from hexafluoropropene and vinylidene fluoride.

thermal environments, the thermal-optical properties of the material must be known so that design engineers can fabricate spacecraft hardware. Six Fluorel samples have been irradiated with electromagnetic energy in the solar- and infrared-wavelength ranges to provide these data. The reflectance, transmittance, absorptance, and emittance of Fluorel were either measured or calculated. This report contains the theory and definitions required to use these data and introduces and applies the mean-value technique to thermal-optical properties. The samples, the sample preparation, and the test procedures are described, and the engineering significance of the thermal-optical data is discussed.

THEORY AND DEFINITIONS

The interdisciplinary literature available to the scientific community has the same terms with different meanings as well as the same meaning for different terms, and the terms and meanings have authoritative sponsorship (refs. 1 and 2). Therefore, the definitions of these terms are presented as completely and consistently as possible to eliminate semantics, to avoid confusion, and to clarify the test results.

For this study, energy was transported as electromagnetic waves. Further, the energy has a wavelength and temperature distribution. If (1) radiant energy is defined as the energy leaving a material, (2) irradiant energy is defined as the energy impinging a material, and (3) both radiant and irradiant energy have angular dependence, the thermal-optical properties of a material will have an angular dependence. Perfect radiators or perfect absorbers (black bodies) are an exception. A property is defined as directional if the energy is measured about a small solid angle at a specified angle and the angular dependence of the property is explicit. When the energy is collected at a unit-hemispherical envelope covering the material or the material is irradiated with a hemispherical source, the property is defined as hemispherical and the angular dependence is implicitly included.

A beam of electromagnetic energy is monochromatic if the energy of the beam is concentrated in a narrow wavelength interval. Usually, the energy is distributed continuously in the interval; however, the energy is identified in test reports with a single wavelength or center frequency for the interval. Thermal-optical properties are defined as spectral to show the properties' wavelength dependence about a wavelength interval. The total thermal-optical property of a material means that the energy contributed from all wavelengths has been included implicitly. The total property can be measured in the laboratory for a specific energy distribution, or the total property can be calculated using the desired energy distribution and the measured, or calculated, spectral property.

When a beam of electromagnetic energy impinges the boundary between two media that have different velocities of propagation, the beam is separated into reflected and transmitted components. By definition, the reflectance is the ratio of the energy reflected at the boundary to the energy incident at the boundary. Transmitted energy travels into or through the second medium, depending on the material and the material thickness. External transmittance (a measured property) is the ratio of the energy transmitted through the material to the incident energy, and internal transmittance (a calculated property) is the ratio of the energy incident on the second internal surface to the energy leaving the first internal surface (ref. 3).

Absorptance is defined as the ratio of the electromagnetic energy absorbed by a material to the energy incident on the material (ref. 3). Because problems are associated with measuring absorbed energy, absorptance is calculated using the energy-balance equation

$$\alpha = \frac{I_o - \left(I_\rho + I_\tau\right)}{I_o} \tag{1}$$

where α is the absorptance, I_o is the incident energy, I_ρ is the reflected energy, and I_τ is the transmitted energy. By substituting the preceding definitions for reflectance ρ and transmittance τ into equation (1), the absorptance α becomes

$$\alpha = 1 - \rho - \tau \tag{2}$$

The absorptance will have the characteristics of reflectance and transmittance. For example, if the reflectance and transmittance are spectral, the absorptance is spectral; if the reflectance and transmittance are total, the absorptance is total; and so forth.

Emittance is defined as the ratio of the electromagnetic energy radiated from a sample to the electromagnetic energy radiated from a perfect radiator at the same thermodynamic and geometric conditions. Although a perfect radiator is independent of sample geometry, the sample geometry must be included because a laboratory sample of a perfect radiator is seldom available.

Several points that must be clarified before the thermal-optical data presented in this report can be used accurately for thermal analysis are summarized as follows.

1. Reflectance, transmittance, absorptance, and emittance are not material-property coefficients because they are collected for a specific sample thickness and surface configuration. These values are not always equal to the material-property coefficients; therefore, the equality must be demonstrated and not assumed.

2. Reflectance, transmittance, absorptance, and emittance usually do not have the same directional dependence.

a. When reflectance and transmittance are discussed, directional dependence must be specified for irradiant and radiant energy; that is, both irradiant and radiant energy may be measured over any part of a solid angle in one or more directions. Energy may be incident either from one direction about a small solid angle or from several directions. The radiant energy coming from a sample may be measured in one direction about any solid angle or about small solid angles in several directions.

Directional properties cannot be resolved from hemispherical properties; however, if the energy is measured about small solid angles for specific directions, the energy can be calculated for one direction about any solid angle up to 2π steradians.

b. The directional dependence of absorptance is related to irradiated energy, and the directional dependence of emittance is related to radiant energy. Kirchhoff's law (ref. 2) states that, under certain conditions, absorptance and emittance are equal. The directional dependence (or independence) dictates the conditions for equality.

Because electromagnetic energy is a function of wavelength, direction, and temperature, the material properties required for thermal analysis can be calculated using the methods of statistical thermodynamics and can be defined as mean values. The mean value (ref. 4) for a discrete variable U and a discrete probability distribution W is defined by

$$\overline{U} = \frac{\sum_i U_i W_i}{\sum_i W_i} \tag{3}$$

For a continuous variable and distribution, the mean value (ref. 5) becomes

$$\overline{U} = \frac{\int_U UW\,dU}{\int_U W\,dU} \tag{4}$$

when $\overline{U}$ is the total property, U is the spectral property, and W is the spectral distribution.

For two discrete variables U and V, a parameter P(U, V), and a discrete probability distribution W(U, V), the mean value (ref. 5) $P(\overline{U}, \overline{V})$ is

$$P(\overline{U}, \overline{V}) = \frac{\sum_i \sum_j U_{ij} V_{ij} W\left(U_i V_j\right)}{\sum_i \sum_j W\left(U_i V_j\right)} \tag{5}$$

If the variables and distribution are continuous, then

$$P(\overline{U}, \overline{V}) = \frac{\int_U \int_V P(U, V) W(U, V)\,dU\,dV}{\int_U \int_V W(U, V)\,dU\,dV} \tag{6}$$

when $P(\overline{U}, \overline{V})$ is the total hemispherical property, U is the spectral property, V is the directional property, and $W(U, V)$ is the source distribution of interest.

Each problem in thermal analysis dictates which thermal-optical property is required in order to find a solution; therefore, the idea of calculating mean values using basic laboratory data is particularly attractive. If all the values required for a detailed thermal analysis could be measured in the laboratory, the time and cost would be prohibitive. However, spectral data that show wavelength dependence and directional data that show angular dependence can be measured parametrically in the laboratory. These measured data can be substituted into the mean value equations (3), (4), (5), or (6) and can be used to calculate the desired thermal-optical property. If this approach is applied only to reflectance, eight different reflectance values can be calculated from one set of measured reflectance data.

The integrals, or summations, can be iterated, or the order of integration variables can be interchanged to facilitate calculations. Kaplan (ref. 6) proved that, if a multivariable function is continuous in a closed region and the region is identified by increasing inequalities of the variables, the integral (or sum, for discrete parameters) can be evaluated by any chosen order of variables. These conditions are satisfied by thermal-optical properties and have been shown by Edwards and Roddick (ref. 7) to be experimentally true.

TEST-SAMPLE DESCRIPTION AND TEST PROCEDURE

The laboratory sample number, sample thickness, material description, form, and possible uses of Fluorel are listed in table I for all test samples. Fluorel compounds are hexafluoropropene and vinylidene fluoride, but the specific formulas are not available because they are proprietary. Samples 1A, 1B, and 1C were designated by the manufacturer as L-3203-6 or its derivative. All samples were a Fluorel composition, except for sample 1C, which had a glass fabric substrate. Samples 2A, 2B, and 2C, designated 1059 by the manufacturer, had a different thickness and different characteristics because of fabrication. Sample 2C was the only foam configuration tested.

The samples were examined with a 10-power lens to verify a testable surface condition, were cut to the required size for the test equipment described in the appendix, were cleaned with Freon (if necessary), and were installed in the following manner. The solar-wavelength transmittance-test samples were clamped into the sample holder, and the holder was installed in the test equipment. The solar-wavelength reflectance-test samples were taped to a simulating black body that was fastened magnetically to the reflectance-test sample holder. The infrared-wavelength test samples were coated on one side with silver paste to ensure thermal contact with the coolant, and the coated side was placed toward the interior of a water-cooled sample holder (appendix). A sample-retaining ring held the sample in place.

Anomalies were not apparent in the test materials nor encountered during the test. Sample temperatures in the heated cavity were slightly higher than desirable for spacecraft simulation. However, this condition was anticipated because the samples were dielectric materials that had small heat-transfer coefficients. Consequently, the reduced heat transfer across the sample caused the irradiated surface temperature of the sample to stabilize at a higher equilibrium value. The test facility and the detailed test procedures are described in the appendix.

TABLE I. - FLUOREL TEST-SAMPLE SUMMARY

Sample number	Material description	Sample thickness, cm	Form	Possible use of material
1A	L-3203-6	0.091	Thin sheet	Belts, electrical harnesses, boots, and bladder material
1B	L-3251-3; an L-3203-6 derivative	.178	Thin sheet	Coating for gloves and boot soles, hoses, and tubing
1C	RL 3489; 4190B Beta-glass substrate with L-3203-6 coating, 20 percent by weight; cured at 394.3° K for 4 hr	.025	Fabric	Pads and duct covers; primarily flameproofing material
2A	1059	.041	Thin sheet	Hoses, electrical harnesses, boots, tubing magnets, and oxygen masks
2B	1059	.178	Thin sheet	Same as for 2A
2C	1062 open-cell foam without skin; a 1059 derivative	.076	Foam sheet	Seat cushions, shock absorbers instrument cases, and eyepieces

DATA PRESENTATION

The measured and calculated data collected for the samples identified in table I are presented in tables II to V. These data quantify the thermal-optical properties of Fluorel that are required to complete a thermal analysis. Table II contains the solar, spectral, directional (15°), hemispherical reflectance and transmittance measured in the laboratory for the six test samples. Solar means the test-wavelength range from 0.24 to 2.65 micrometers. Spectral denotes a test-wavelength interval throughout the solar-wavelength range. Directional (15°) means the irradiant energy incident at 15°. Hemispherical means the radiant energy was collected at a hemispherical envelope over the test sample. The absorptance data presented in table II were obtained by substituting the reflectance and transmittance from table II into the energy-balance relation (eq. (2)).

TABLE II. - MEASURED SOLAR. SPECTRAL, DIRECTIONAL, HEMISPHERICAL REFLECTANCE, TRANSMITTANCE, AND ABSORPTANCE

(a) Samples 1A, 1B, and 1C[a]

Wavelength, μm	Sample 1A		Sample 1B			Sample 1C		
	Reflectance, ρ, percent	Absorptance, α, percent	Reflectance, ρ, percent	Absorptance, α, percent	Transmittance, τ, percent	Reflectance, ρ, percent	Absorptance, α, percent	Transmittance, τ, percent
0.25	9	91	7	93	0	11	88.5	0.5
.28	9	91	7	93	0	11	88.5	.5
.32	9	91	7	93	0	23	75.0	2.0
.36	11	89	8	92	0	34	61.0	5.0
.40	13	87	10	90	0	46	45.0	9.0
.45	17	83	13	87	0	55	33.0	12.0
.50	22	78	16	84	0	63	22.0	15.0
.56	29	71	22	78	0	67	15.0	18.0
.63	37	63	31	69	0	69	11.0	20.0
.71	43	57	38	62	0	69	10.0	21.0
.79	49	51	44	56	0	68	15.0	17.0
.89	55	45	50	50	0	68	20.0	12.0
1.00	54	46	50	50	0	67	14.0	19.0
1.12	52	48	49	50	1	67	10.0	23.0
1.26	47	53	44	55	1	66	9.0	25.0
1.41	40	60	36	63	1	66	8.0	26.0
1.59	30	70	28	70	2	65	8.0	27.0
1.78	23	77	21	77	2	64	8.0	28.0
2.20	15	85	14	84	2	63	9.0	28.0
2.24	9	91	8	90	2	60	7.0	27.0
2.51	6	94	6	94	0	54	21.0	25.0

(b) Samples 2A, 2B, and 2C[a]

Wavelength, μm	Sample 2A		Sample 2B		Sample 2C		
	Reflectance, ρ, percent	Absorptance, α, percent	Reflectance ρ, percent	Absorptance, α, percent	Reflectance, ρ, percent	Absorptance, α, percent	Transmittance, τ, percent
0.25	6	94	6	94	2	97.2	0.8
.28	6	94	6	94	3	93.0	4.0
.32	8	92	6	94	8	90.0	2.0
.36	11	89	6	94	4	93.5	2.5
.40	11	89	6	94	3	94.0	3.0
.45	10	90	6	94	3	95.0	2.0
.50	8	92	6	94	3	96.0	1.0
.56	5	95	6	94	3	96.0	1.0
.63	5	95	6	94	3	96.5	.5
.71	5	95	6	94	2	97.5	.5
.79	5	95	6	94	2	97.5	.5
.89	5	95	6	94	2	97.5	.5
1.00	5	95	6	94	3	97.0	.0
1.12	5	95	6	94	3	96.5	.5
1.26	5	95	6	94	3	96.5	.5
1.41	6	94	6	94	3	96.5	.5
1.59	6	94	6	94	3	96.5	.5
1.78	6	94	6	94	3	96.5	.5
2.20	6	94	6	94	3	96.0	1.0
2.24	5	95	6	94	3	96.0	1.0
2.51	5	95	6	94	3	96.0	1.0

[a]Table I contains sample identification; angle of incidence is 15°.

TABLE III. - MEASURED INFRARED, SPECTRAL, HEMISPHERICAL, DIRECTIONAL REFLECTANCE

Wavelength, μm	Angle of reflectance, deg				
	15	25	45	60	70
	Reflectance, percent				
Sample 1A[a]					
2.8	28	(b)	(b)	(b)	32
3.1	24	24	25	26	27
3.6	22	(b)	(b)	(b)	28
4.0	25	25	27	30	32
4.5	25	(b)	(b)	(b)	32
5.0	16	16	17	20	23
5.6	12	(b)	(b)	(b)	19
6.3	9	9	10	12	15
7.1	8	(b)	(b)	(b)	13
7.9	7	7	8	10	13
8.9	8	(b)	(b)	(b)	15
10.0	10	11	11	14	18
Sample 2A[a]					
2.8	12	(b)	(b)	(b)	16
3.2	12	12	12	13	16
3.6	12	(b)	(b)	(b)	15
4.0	12	13	13	14	16
4.5	13	(b)	(b)	(b)	16
5.0	14	15	15	15	17
5.6	16	(b)	(b)	(b)	17

[a]Table I contains sample identification.

[b]Data not measured.

TABLE III. - MEASURED INFRARED, SPECTRAL, HEMISPHERICAL, DIRECTIONAL REFLECTANCE - Concluded

Wavelength, μm	Angle of reflectance, deg				
	15	25	45	60	70
	Reflectance, percent				
Sample 2A[a] - Concluded					
6.3	17	17	17	17	18
7.1	19	(b)	(b)	(b)	19
7.9	20	20	20	20	20
8.9	24	(b)	(b)	(b)	(b)
10.0	24	25	25	24	25
Sample 2B[a]					
2.8	6	(b)	(b)	(b)	29
3.2	5	6	7	8	29
3.6	4	(b)	(b)	(b)	27
4.0	4	5	6	8	26
4.5	6	(b)	(b)	(b)	29
5.0	8	8	8	10	25
5.6	8	(b)	(b)	(b)	24
6.3	14	15	15	16	19
7.1	16	(b)	(b)	(b)	27
7.9	18	18	18	19	28
8.9	19	(b)	(b)	(b)	26
10.0	23	23	24	25	33

[a]Table I contains sample identification.
[b]Data not measured.

TABLE IV. - CALCULATED INFRARED, TOTAL, HEMISPHERICAL, DIRECTIONAL REFLECTANCE

Angle of reflectance, deg	Sample number[a]		
	1A	2A	2B
	Total reflectance, percent		
15	17	16	10
25	17	16	11
45	18	16	12
60	20	16	12
70	23	18	26

[a]Table I contains sample identification.

TABLE V. - CALCULATED SOLAR, TOTAL, DIRECTIONAL (15°), HEMISPHERICAL PROPERTIES AND INFRARED, TOTAL, HEMISPHERICAL REFLECTANCE AND EMITTANCE

Sample number[a]	Solar			Infrared[b]		
	Reflectance, ρ, percent	Transmittance, τ, percent	Absorptance, α, percent	Reflectance, ρ, percent	Emittance, ϵ, percent	α/ϵ
1A	34	0	66	7	93	0.71
1B	30	0	70	(c)	(c)	(c)
1C	62	18	20	(c)	(c)	(c)
2A	6	0	94	6	94	1.00
2B	6	0	94	5	95	.99
2C	3	1	96	(c)	(c)	(c)

[a]Table I contains sample identification.
[b]Infrared incidence was hemispherical.
[c]Data not measured.

Table III contains the infrared, spectral, hemispherical, directional reflectance measured in the laboratory for samples 1A, 2A, and 2B. For these data, infrared means the test-wavelength range from 2.65 to 10.6 micrometers, hemispherical denotes that the irradiant energy was hemispherically incident at the sample, and directional means the radiant energy was measured at 15°, 25°, 45°, 60°, and 70°. Numbers are missing from this table because data were not measured at selected wavelengths to reduce laboratory testing.

Table IV contains the calculated infrared, total, hemispherical, directional reflectance and table V contains the calculated solar, total, directional (15°), hemispherical properties and the infrared, total, hemispherical reflectance and emittance. Total denotes that energy from the complete-wavelength range is included. Total values were calculated for the solar-wavelength range using a Johnson spectral distribution (ref. 8), the data in table II, and equation (3). Total values (table IV) were calculated for the infrared wavelength by substituting Planck's spectral distribution and the values in table III into equation (4). Planck's distribution for this equation is

$$W(T,\lambda) = \frac{C_1}{\lambda^5\left(e^{C_2/\lambda T} - 1\right)} \frac{\text{watts}}{\text{micrometer (meter)}^2}$$

where T = temperature, 683° K

λ = wavelength, micrometers

$C_1 = 3.7405 \times 10^8 \frac{\text{watts (micrometers)}^4}{(\text{meters})^2}$

C_2 = 14 387.9 micrometer °K

e = 2.718

Table V contains the infrared, total, hemispherical reflectance and emittance. The emittance values were calculated using Planck's spectral distribution, the data in table III, and equation (5). The infrared reflectance was calculated using equation (2). The absorptance-to-emittance ratios (α/ϵ) are presented for convenience.

RESULTS AND DISCUSSION

A material that functions as a thermal barrier would be expected to have a high absorptance. The mean values presented in table V prove that Fluorel does have a high absorptance. All test samples except 1C absorbed more than 66 percent of the incident energy in the solar-wavelength range. For the infrared-wavelength range (table V), the absorptance values for samples 1A, 2A, and 2B are 93, 94, and 95 percent, respectively. Sample 1A has a spectral absorptance of 45 percent at 0.89 micrometer (table II).

The other four Fluorel samples have even higher spectral absorptance. Because Fluorel is a dielectric material and its heat capacity is relatively high, Fluorel will perform as an effective heat sink.

Sample 1C had a Beta-glass substrate, and the data collected for this sample are characteristic of glass-fabric materials and not of Fluorel. The measured reflectance and transmittance are higher in the visible and near-infrared ranges than for any other sample tested. The absorptance presented in table II is less than 20 percent for the wavelengths longer than 0.50 micrometer.

The spectral properties of Fluorel, as for any solid material, are a function of geometry, molecular structure, and surface "roughness" (ref. 2). These parameters vary with fabrication technique and material application. Fluorel L-3251-3 is a derivative of L-3203-6; therefore, the thermal-optical properties should be similar, and the absorptance data for samples 1A and 1B (fig. 1) verify this similarity. Sample 1B (L-3251-3) transmitted energy in the near-infrared range (table II), but the amount of energy transmitted was not evident in the transmittance mean value (table V), and the reflectance of sample 1B was less than the reflectance of sample 1A (fig. 2). These differences were attributed to surface finish rather than to molecular structure or sample thickness.

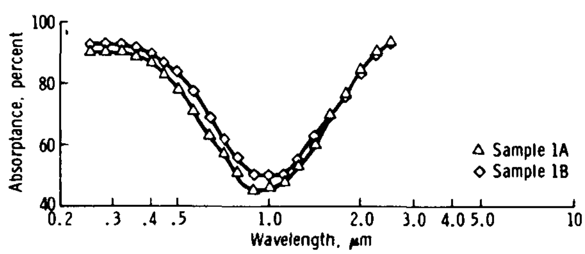

Figure 1. - Absorptance as a function of wavelength for samples 1A and 1B (data are obtained from table II).

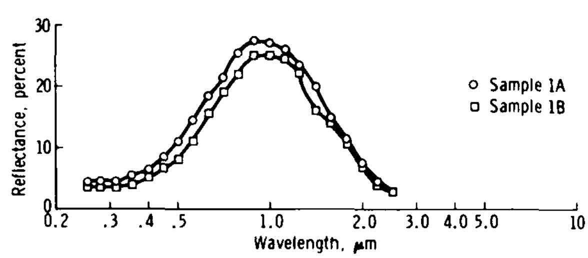

Figure 2. - Reflectance as a function of wavelength for samples 1A and 1B (data are obtained from table II).

Samples 2A and 2B are opaque even though sample 2B is not as thick as sample 2A. Both samples are Fluorel 1059, but sample 2A has a smoother finish than sample 2B. Generally, the reflectance (fig. 3) of sample 2A was higher and the absorptance (fig. 4)

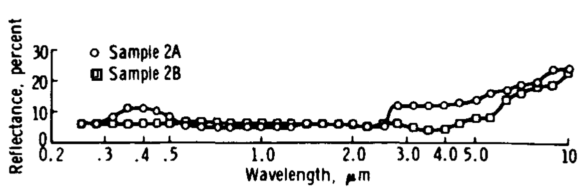

Figure 3. - Reflectance as a function of wavelength for samples 2A and 2B (data are obtained from table II (solar) and table III (infrared)).

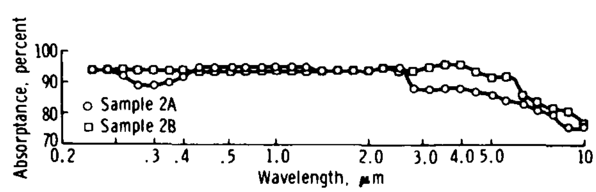

Figure 4. - Absorptance as a function of wavelength for samples 2A and 2B (data are obtained from table II (solar) and table III (infrared)).

lower than for sample 2B. This evaluation clearly demonstrates that fabrication affects thermal-optical properties; consequently, an accurate thermal analysis will require that the spectral values be measured on Fluorel hardware.

The absorptance, emittance, and absorptance-to-emittance (α/ϵ) values presented in table V are the required values for thermal analysis. These data were calculated for specific distributions, and these data must be recalculated if a different energy distribution is anticipated because the α/ϵ ratio includes, but does not show explicitly, the spectral and directional characteristics for a material. The α/ϵ ratios for samples 2A and 2B are 1.00 and 0.99, respectively. This difference is less than the experimental error of the data collected. However, the spectral and directional properties that were collected and calculated for these two samples are significantly different. Although sample 2A has a definite solar-wavelength dependence with a maximum at 0.36 to 0.40 micrometer, sample 2B has the same reflectance for all wavelengths (table II). The Johnson distribution has a maximum at 0.5 micrometer where the two samples have the same spectral reflectance. Consequently, the samples have the same total reflectance of 6 percent (table V). If the mean reflectance value had been calculated for a spectral distribution with a maximum at 0.36 to 0.40 micrometer, sample 2A would have a higher total reflectance, but sample 2B would have the same value. The infrared reflectance also varies as a function of wavelength. The measured 15° reflectance values for samples 2A and 2B at 4 micrometers are 12 and 4 percent, respectively (table III). Both are wavelength dependent at 15° (see table III for the change in reflectance from 2.65 to 10.6 micrometers). The mean values of reflectance presented in table IV for a Planck distribution at 15° are 16 percent for sample 2A and 10 percent for sample 2B. Although the relative difference is only 5 percent, the absolute difference is 37.5 percent; this difference must be considered significant. The calculated mean value of the reflectance has an even greater difference at 70°, where the reflectance was 18 percent for sample 2A and 26 percent for sample 2B (table IV). This variation is not readily apparent from the infrared data in table V; however, the thermal environment will dictate the significance of these differences. For example, the Planck distribution for a temperature of 720° K, has a peak at 4 microns; therefore, the materials will stabilize at different temperatures and sample 2B will be hotter than sample 2A. If the emitted radiation at 70° is more important to a particular geometry or environment, then sample 2A would radiate more energy than sample 2B.

This evaluation shows that the thermal-optical properties can vary when the thermal environment changes, and, if an accurate analysis is required, this variation must be considered. The α/ϵ values shown in table V were calculated for Johnson and Planck distributions, and the values must be recalculated if a different thermal environment is anticipated.

CONCLUDING REMARKS

Two basic Fluorel compounds and four Fluorel derivatives were irradiated with electromagnetic energy in the wavelength range from 0.24 to 10.6 micrometers to measure the spectral reflectance and transmittance. These data were used to calculate the absorptance and emittance as functions of wavelength and direction. Then, the measured and calculated data were used to calculate mean values for a Johnson solar-spectral distribution and a 683.2° K Planck distribution. By removing the wavelength and angular dependence to yield solar, total, hemispherical absorptance for angle of incidence of 15° and to yield total, infrared, hemispherical emittance for hemispherical incidence, the absorptance-to-emittance ratios for these distributions were 0.71, 0.99, and 1.00.

This investigation indicated that Fluorel is an effective heat sink; that the spectral and directional material properties and the specific environments must be known before the absorptance-to-emittance ratio can be calculated; that the material properties, as with most solid material, vary with fabrication methods; and that mean-value techniques developed in statistical thermodynamics can be applied to material properties measured by radiation-transfer techniques.

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National Aeronautics and Space Administration
Houston, Texas, November 12, 1971
914-50-80-01-72

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APPENDIX

EQUIPMENT AND TEST PROCEDURE

A block diagram of the test equipment is illustrated in figure A-1. The equipment consists of a source-transfer optical system, a single-beam double-pass prism monochromator, a servomirror assembly, and an integrating sphere.

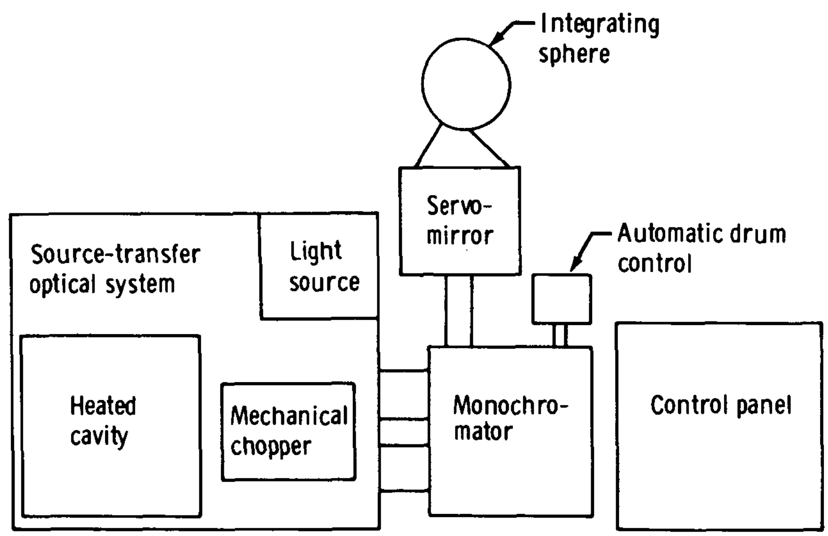

Figure A-1. - Block diagram of the equipment used to measure the reflectance and absorptance of materials.

SOLAR-WAVELENGTH RANGE

The source-transfer optical system generates a solar test spectrum by use of a mercury lamp for the wavelength range from 0.24 to 0.42 micrometer and by use of a tungsten lamp for the wavelength range from 0.42 to 2.7 micrometers. The energy from the lamp is reflected from a concave mirror to a vertical slit and a circular aperture. Then, the beam is interrupted by a mechanical chopper. The electromagnetic energy can be filtered as it leaves the source-transfer system and before it enters the monochromator.

After entering the monochromator, the beam passes through an adjustable slit and is collimated by an off-axis parabolic mirror. Then, the beam is dispersed by a quartz prism, reflected by a litromirror, and retraces its path through the prism and collimator. The litromirror movement controls the pass wavelength for the monochromator. Finally, the beam is reflected by a mirror and leaves the monochromator through an adjustable exit slit and enters the servomirror assembly.

The servomirror assembly consists of two concave and one flat-surface mirror. All three mirrors are used to measure reflectance, but only two mirrors are used to measure transmittance. The flat-surface mirror is moved to direct the beam to one of the two concave mirrors. One concave mirror directs the beam to strike the sample. Then, the beam is reflected by the sample to the integrating-sphere wall where the reflected energy is recorded, either with a photomultiplier, for the wavelength range from 0.24 to 0.67 micrometer, or by a lead sulfide detector for the wavelength range from 0.67 to 2.65 micrometers. The second concave mirror directs the beam to the sphere wall where the incident energy of the beam is measured. The two energies are compared to determine the sample reflectance.

An alternate method for measuring the incident energy is to rotate the sample holder 180° so that the beam strikes a freshly smoked, highly reflective magnesium oxide surface. For the test spectrum, the spectral reflectance that was measured by the two methods varied less than 2 percent. This variation is considered consistent with the known experimental error of the equipment.

For transmittance measurements, the flat-surface mirror directs the beam to one concave mirror. The beam energy is measured with the sample at the entrance of the integrating sphere and also with the sample removed. The two energy levels are compared to determine the transmittance of the sample.

INFRARED-WAVELENGTH RANGE

A heated-cavity reflectometer that is used to measure the spectral reflectance for the wavelength range from 2.65 to 10.6 micrometers is shown in figure A-1. A schematic of the cavity and the sample holder is presented in figure A-2. The cylindrical cavity is a 16.5-centimeter-diameter nickel tube with a 15.2-centimeter inside diameter. The tube walls and one endplate are 0.64-centimeter thick. The second endplate is 0.97-centimeter thick and has a 5.72-centimeter-diameter sample-holder port. A rectangular sample viewport, 3.18 by 4.06 centimeters, is located in the tube wall 10.80 centimeters from the end that contains the entrance port. The cavity walls, which have ten 60° grooves per 2.54 centimeters, were oxidized at 1255.4° K and then were painted with a high-temperature black paint to increase the wall emittance. The cavity surfaces are heated electrically, and the isothermal surface temperature of the cavity wall is maintained by controlling the power supplied to each heater.

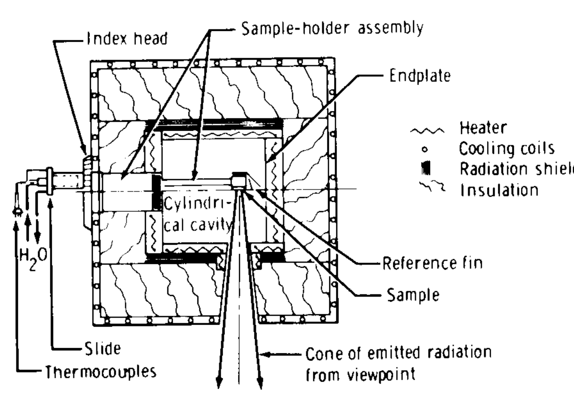

Figure A-2. - Schematic of the heated cavity and the sample holder.

The cavity provided a hemispherical source at 683.2° K to irradiate the samples and a platinum reference. Initially, the energy beam that comes directly from the cavity or is reflected by the sample or the reference impinges a first-surface gold-coated mirror, then traverses the same path used by the energy from the solar sources. For the heated-cavity wavelength range, a sodium chloride prism is used, and a potassium bromide thermocouple detector replaces the integrating sphere.

Spectral data are collected by viewing first the sample and then the cavity. An alternate procedure is to view the sample and then the platinum reference. The ratio of the energy reflected from the sample to the energy reflected from the cavity (or reference) has been defined as the reflectance.

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16. Abstract

Fluorel L-3203-6 and 1059 and four Fluorel derivatives were irradiated monochromatically and hemispherically with electromagnetic energy in the solar- and infrared-wavelength range to determine the thermal-optical properties that are required for engineering analysis. The thermal-optical properties have been measured and analyzed, and the resulting data have been tabulated for convenient engineering use. The results prove that the electromagnetic-energy distribution and the measured reflectance and transmittance of materials can be used to calculate several mean values, which are the total and hemispherical thermal-optical properties. The test results also illustrate that Fluorel effectively absorbs energy in the solar- and infrared-wavelength range. In addition, the results demonstrate that fabrication alters the thermal-optical properties of Fluorel.

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