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THE MEASUREMENT OF DIFFUSE REFLECTANCE OF CLOTH AND SKIN SAMPLES

by:

Leo J. Krolak
Thomas P. Davis

Division: Special Programs

Division Head: H. A. Blair

Section: Flash Burns

Section Head: H. D. Kingsley

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THE MEASUREMENT OF DIFFUSE REFLECTANCE
OF CLOTH AND SKIN SAMPLES

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ABSTRACT

The diffuse reflectances of various samples of cloth and excised pig skin were determined using a Coblentz type reflectometer which was constructed for use in the range 0.4μ to 2.6μ .

It was necessary to make preliminary reflection readings on each sample, in the range from 0.4μ to 0.7μ , with a General Electric automatic recording spectrophotometer so that a correction factor could be determined to correct for energy losses suffered in the hemispherical reflectometer.

A modification was suggested on the basis of errors brought out in the technique used.

NOTE: This study was carried out through the facilities of the University of Rochester Atomic Energy Project, under contract with the U. S. Atomic Energy Commission, and a portion of its expenses defrayed under grant from the Quartermaster Corps, U.S. Army.

Introduction

The problem involved in this investigation was the determination of the diffuse spectral reflectance of various types of cloth which varied in weave, weight, and color; also, the determination of the diffuse spectral reflectance of excised porcine skin. In general, the method consisted of comparing the deflections resulting from collecting the diffuse energy reflected from a sample of known spectral reflectance and from an unknown sample. It was necessary to construct a reflectometer which would collect the energy from a sample reflecting into a solid angle of 2π steradians and focus it on a suitable receiver.

The data obtained with this apparatus will be used (5) to evaluate the protective effects of various cloths on pigs subjected to thermal radiation.

Apparatus and Equipment

A block diagram of the equipment used appears in figure 1. All of the apparatus, except the hemispherical reflectometer, has been previously described (4) in detail. Light from the source S, a General Electric 10 v 18 amp spectroscopic lamp, was focussed on the entrance slit of the Perkin-Elmer model 83 universal monochromator by means of two spherical mirrors M_1 and M_2 . The monochromator radiation passing through the exit slit of the monochromator was focussed on the sample holder of the reflectometer by means of two off-axis parabolic mirrors M_3 and M_4 and the plane mirror M_5 .

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REFLECTOMETER OPTICAL SYSTEM

Figure 1

Figure 2 is a cross section of the hemispherical reflectometer. Light from the second parabolic mirror M_4 was deviated about 90° by mirror M_5 and focussed on the sample. The plane mirror, made by the Bausch and Lomb Optical Co., Rochester, New York, was mounted on a ball and socket universal mount to facilitate focussing the incoming beam on the sample.

The Naval Gun Factory, Washington, D. C., made the 6 in. diameter .140 in. thick, hemispherical mirror which was ground and polished on the inner surface with a $3/4$ in. diameter hole drilled in the apex to allow the monochromatic radiation to enter. The inner surface of the hemisphere was aluminized by the Evaporated Metal Film Corp., Ithaca, New York.

The hemisphere was mounted in a brass holder, figure 3, and held in place by means of a brass top which held the sample port and PbS cell, a 4mm by 4mm Ektron detector with butyl methacrylate overcoating, made by Eastman Kodak Co., Rochester, New York. The brass holder and hemisphere were placed on an adjustable tripod as shown in the photograph, figure 3. Figure 4 is a cross-section view of the brass top through the sample holder and PbS mount.

On either side of the center of curvature, at a distance of $9/32$ in. from it, were located the sample hole and the hole for the PbS cell mount. In order to get a very fine movement on either side of the plane formed by the rim of the hemisphere without rotating the PbS cell, it was mounted at the end of a differential screw. The sample holder had a $7/16$ in. hole drilled through it so that any transmitted energy would

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Figure 2

REFLECTOMETER OPTICAL SYSTEM

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Figure 3

1. Off-axis parabolic mirror M_4
2. Flat mirror, M_5
3. Brass mounting for hemisphere
4. Adjustable tripod
5. Sample holder
6. PbS cell mount

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CROSS SECTION OF SAMPLE HOLDER AND CELL MOUNT

Figure 4

not affect the readings. The sample, which was pasted at the end of the holder, was positioned in the same plane each time by means of the shoulder on the holder which was the same for the MgO standard sample except for the hole through the center. The sample hole and detector mount were made in a slide which fit into the brass top. The only purpose for the slide was to position the sample accurately.

A General Electric automatic recording spectrophotometer, owned by the Bausch and Lomb Scientific Laboratory in Rochester, New York, was used to find the spectral reflectance of the various samples in the range from $.400 \mu$ to $.700 \mu$. Because the beam of light of this instrument was about 1 in. in diameter, it was necessary to cut $1 \frac{1}{2}$ in. diameter skin samples which were later recut to $\frac{1}{4}$ in. diameter samples for use with the hemispherical reflectometer. Figure 5 is a cross-sectional view of the holders used for the skin sections.

Method

The reflectometer used in this study was patterned after models made by W. W. Coblentz (1), J. A. Sanderson (7), and W. L. Derksen and T. I. Monahan (3). The method used was similar to that of the latter authors.

Any object placed to one side of the center of curvature of a hemispherical mirror will be imaged at an equal distance on the opposite side of the center of curvature. Since the sample port was at the same distance from the center of curvature as the PbS detector, any light striking the sample was focussed on the PbS cell by the hemispherical mirror. The monochromatic energy incident on the sample, I_0 , was altered in several ways before reaching the detector. There was the reflection

2X Actual Size

Actual size

Sample holder for General Electric Instrumen.

Sample holder for hemispherical instrument

Figure 5

of the sample, the hemispherical mirror, and the PbS cell, r_x , r_h , and r_c respectively. Any losses due to energy passing out through the 3/4 in. port and to imperfect focussing could be lumped into one constant (1-K).

Therefore, the energy absorbed by the receiver was

$$I_{cx} = r_c r_x r_h K I_o$$

K was considered to be independent of wavelength. In the same manner, the energy absorbed by the cell with the MgO sample in place was

$$I_{cm} = r_c r_m r_h K I_o$$

The ratio of the above two equations was equal to the ratio of the respective deflections on the recorder with the sample and MgO standard in place or

$$\frac{I_{cx}}{I_{cm}} = \frac{D_x}{D_m} = \frac{r_x K_x}{r_m K_m}$$

Therefore

$$r_x = r_m \frac{D_x K_m}{D_m K_x}$$

In practice, the standard coated MgO sample (6) was run from 0.4μ to 2.6μ with a given slit width and amplification. The same treatment was applied to the sample for which the spectral reflectance was being investigated. The ratio of the two deflections at a given wavelength gave the uncorrected reflectance of the sample at that wavelength.

The reflectance of the sample was then found between 0.4μ and 0.7μ with the General Electric recording spectrophotometer. The ratio of the reflectances found with the General Electric reflectometer and the hemispherical reflectometer was determined at specific wavelengths between

Table 1

Wavelength (μ)	$\frac{D_x}{D_m}$	G. E. Deflection	$\frac{K_m}{K_x}$	MgO Reflection r_m	$\frac{r_m K_m D_x}{K_x D_x}$ (%)	Relative distribution 24" arc	r_x X col. 7 (%)
1	2	3	4	5	6	7	8
.404	.370	.377	1.06	.966	41.4	1.004	41.3
.409	.333	.358	1.11	.966	37.0	1.004	37.1
.414	.324	.339	1.08	"	36.0	.970	34.9
.420	.316	.323	1.06	"	35.1	.950	33.3
.426	.295	.317	1.11	.968	32.9	.940	30.9
.432	.294	.327	1.15	"	32.8	.931	30.5
.438	.345	.366	1.10	"	38.4	.928	35.6
.445	.412	.445	1.11	.970	46.0	.924	42.5
.452	.494	.518	1.08	.972	55.2	.919	50.7
.460	.549	.568	1.07	"	61.4	.918	56.4
.467	.547	.587	1.10	.973	61.2	.921	56.4
.475	.566	.595	1.08	.974	63.4	.935	59.3
.484	.571	.597	1.07	.975	64.1	.969	62.1
.493	.539	.592	1.13	"	60.5	.993	60.1
.503	.527	.578	1.13	"	59.1	1.00	59.1
.514	.502	.555	1.13	"	56.2	.995	55.9
.525	.472	.532	1.16	.976	53.0	.983	52.1
.537	.453	.505	1.14	"	50.8	.965	49.0
.549	.423	.475	1.15	"	47.5	.944	44.8
.563	.424	.470	1.14	"	47.6	.905	43.1
.578	.443	.508	1.18	"	49.7	.871	43.3
.594	.479	.558	1.19	.975	53.7	.830	44.6
.610	.517	.629	1.25	"	58.0	.788	45.7
.628	.522	.661	1.30	"	58.5	.743	43.5
.646	.523	.670	1.32	.974	58.5	.682	39.9
.667	.517	.677	1.35	.973	57.8	.614	35.5
.687	.515	.586	1.37	.972	57.6	.560	32.3
		Ave.	1.15				

Table 2

Wavelength (u)	Deflection D_m (mv)	Deflection D_x (mv)	Reflection r_m	$r_x \frac{K D_m}{K D_x}$ (%)	Relative Distribution 24" arc	r_x Col. 6 (%)
1	2	3	4	5	6	7
.504	.38	.20	.975	59.0	1.000	59.0
.563	.81	.33	.976	45.7	.910	41.6
.628	1.35	.72	.975	59.8	.745	44.6
.687	1.81	.91	.972	56.2	.560	31.5
.738	1.99	.98	.967	54.7	.454	24.8
.766	1.98	.95	.965	53.2	.425	22.6
.796	1.94	.93	.963	53.0	.404	21.4
.830	2.00	.97	.962	53.7	.376	20.2
.862	2.53	1.15	.961	50.3	.357	18.0
.900	3.63	1.66	.960	50.5	.328	16.6
.942	5.10	2.23	.959	48.2	.300	14.5
.988	6.55	2.63	.958	44.3	.290	12.8
1.032	7.72	3.29	.957	46.9	.268	12.6
1.079	8.66	3.79	.957	48.2	.244	11.8
1.124	9.24	3.88	.955	46.1	.225	10.4
1.152	9.40	3.53	.954	41.3	.214	8.8
1.174	9.62	2.92	.954	33.4	.208	6.9
1.230	9.72	2.77	.954	31.3	.184	5.8
1.269	9.68	2.99	.954	33.9	.172	5.8
1.318	9.49	2.70	.954	31.3	.155	4.9
1.366	8.23	1.65	.952	21.9	.137	3.0
1.412	8.10	.92	.950	12.4	.129	1.6
1.460	8.08	.84	.950	11.4	.132	1.5
1.508	7.62	.83	.951	12.0	.116	1.4
1.555	7.12	.87	.952	13.3	.104	1.4
1.600	6.61	.90	.950	14.8	.095	1.4
1.646	6.11	.90	.949	16.1	.087	1.4
1.692	5.60	.79	.949	15.4	.079	1.2
1.777	4.81	.61	.948	13.8	.070	1.0
1.862	3.67	.42	.944	12.4	.060	0.7
1.902	3.58	.32	.941	9.7	.058	0.6
1.940	3.41	.30	.941	9.5	.057	0.5
2.012	3.05	.27	.943	9.7	.059	0.6
2.054	2.85	.26	.943	9.9	.055	0.5
2.129	2.43	.22	.943	9.9	.042	0.4
2.199	2.03	.19	.943	10.2	.035	0.4
2.267	1.68	.17	.939	10.9	.033	0.4
2.399	1.11	.08	.934	7.7	.029	0.2

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LOCATION OF SKIN SAMPLES

- ②① Flank
- ②① 12th rib
- ②② Mid-chest
- ②③ Ham
- ②④ Shoulder

Figure 6

The final total reflectances of the pig skin were determined employing the same method used with the cloths.

Results

Figures 7 through 21 are the spectral reflectance curves of the different cloths and of the samples of pig skin. They are identified by numbers for which a description may be found in table 3 and figure 6. The second curve of figure 17 results when column 5 of table 2 is multiplied by column 6. The area under this latter curve divided by the area under the relative spectral curve of the 24 in. arc gives the total reflectance of the cloth when used with the 24 in. arc.

Table 3 is a summary of the cloth and skin samples with a description and the total reflectance using the 24 in. arc as a source.

Discussion of results

In finding the total reflectance of a sample with the 24 in. arc as the source, some error was introduced by finding the reflectance down to only 0.4μ because the arc does emit below this value.

The area under the relative spectral energy curve for the 24 in. arc from 0.4μ to 2.6μ was 84.7 cm^2 and the area from 0.25μ to 0.4μ was 12.9 cm^2 . The area under the reflectance curve for the material with the highest overall reflectance, the 9 oz white cotton sateen, was 63.2 cm^2 . Now, if we assumed that the reflectance of this material below 0.4μ was 100%, this would give an area of 76.1 cm^2 instead of 63.2 cm^2 . The latter area gave a total reflectance of 74.6% ($63.2/84.7$) while the former area resulted in a reflectance of 78% ($76.1/97.6$), a per cent difference of about 4.5%. The actual per cent difference is probably less than 1/2 of

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Figure 8

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Figure 10

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Figure 11

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Figure 12

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Figure 19

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Figure 20

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Table 3

Sample No.	Figure No.	Description	Reflectance with 24" Arc
1.	7	5 oz green oxford, outer component of porous tropical uniform	18.3
2.	7	Ditto, with 25% add-on of flame retardant*	28.3
3.	8	9 oz O. G. sateen, outer component of uniform for temperate climate (combat type)	20.2
4.	8	Ditto, with 25% add-on of flame retardant*	27.5
5.	9	9 oz sateen, special series impregnated with CMC (carboxy methyl cellulose) as binder plus varying amounts of carbon black to deepen shade. Total weight is 9 ± 0.5 oz/yd. ²	3.5
6.	9		6.0
7.	9		27.6
8.	9		59.3
9.	9		74.6
10.	10	Special series of sateens impregnated with CMC (carboxy methyl cellulose) and carbon black, each of approximately the same reflectance, but of different weights /yd. ² i.e. #10-6 oz, #11-8.5 oz, #12-12 oz	7.3
11.	11		7.3
12.	12		7.0
13.	13	Special series of unbleached, undyed cotton oxfords of approximately the same weight (7.3-8.3 oz/yd. ²) but of varying porosity (cover factor 44-49)	65.8
14.	14		66.6
15.	15		68.5
16.	15		66.4
17.	17		64.9
18.	18	Tubular knit cotton undershirt material, white, of about 3.5 oz/yd. ²	47.3
19.	18	Tubular knit heavy underwear material (50% cotton, 50% wool), unbleached, about 10 oz/yd. ²	49.4
20.	19	Pig skin, flank	35.4
21.	20	Pig skin, 12th rib	43.0
22.	19	Pig skin, mid chest	43.7
23.	19	Pig skin, ham	39.1
24.	21	Pig skin, shoulder	43.8
* H.P.M. - "High Polymer Martin" or polymerized brominated tri-allyl phosphate.			

this or about 2% because, of course, the reflectance below 0.4μ is not 100%. The same can be said for the other samples involved so that the per cent error in the final reflectance figure is of the order of 2%.

After all of the foregoing work had been completed, it was found that the total reflectance of the PbS cell was about 50%. This high reflectance probably introduced some error into the reflectance readings. The amount of energy absorbed by the PbS cell can be expressed by the following geometric progression

$$I_{cx} = r_x r_h a_c K_x I_o + r_x^2 r_h^3 K_x^3 (1-a_c) a_c I_o + r_x^3 r_h^5 K_x^5 (1-a_c)^2 a_c I_o + \dots$$

$$= r_x r_h a_c K_x I_o \sum_{n=0}^{\infty} r_x^n r_h^n K_x^{2n} (1-a_c)^n$$

where I_{cx} = Energy absorbed by cell
 I_o = " incident on sample
 r_x = Reflectance of sample
 r_h = " hemispherical mirror
 a_c = Absorbance of cell

The same series holds for the MgO sample with r_m , the reflectance of the MgO, and I_{cm} , the energy absorbed by the cell with the MgO sample in place, being substituted for r_x and I_{cx} respectively. Simplifying and taking the ratio of the two series

$$\frac{I_{cm}}{I_{cx}} = \frac{D_m}{D_x} \frac{r_m K_m}{r_x K_x} \left[\frac{1 - r_x^2 r_h^2 K_x^2 (1-a_c)}{1 - r_m^2 r_h^2 K_m^2 (1-a_c)} \right]$$

where D_m = Deflection of recorder with MgO sample in place
 D_x = Deflection of recorder with sample in place

or

$$r_x = \frac{r_m D_x K_m}{D_m K_x} \left[\frac{1}{1 + r_m^2 r_h^2 (1-a_c) \left\{ \frac{D_x K_m K_x - K_m^2}{D_m} \right\}} \right]$$

If the absorption of the cell were 1, the fractions in the squared brackets become 1 and the reflectance at any one wavelength is found by the method outlined previously. However, since the PbS cell does reflect some of the light which is incident upon it and since the amount of reflection probably is wavelength dependent, the correction factor applied to the deflection is not constant throughout the spectrum.

In view of the foregoing, it has been decided to develop a system which would obviate the use of the General Electric instrument and make a receiver which is black throughout the region of interest.

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