DETERMINATION OF THE OPTICAL COEFFICIENTS OF TEXTILES

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An instrument with a radiation receiver based on a compensation pyrheliometer has been used to determine the optical coefficients of textile fabrics of various structures and colors.

To study the processes of radiative heat exchange associated with the heating of thin fiber materials such as textiles by the sun's rays, it is necessary to make an experimental determination of the reflectance, absorptance, and transmittance.

In this case, two points deserve special attention: first, the broad spectral composition of the solar radiation at the earth's surface with a considerable fraction (46–69%) in the infrared [1] and, second, the diffuse character of the scattering and emission of fibrous materials having a rough surface.

Under these conditions the calorimetric method is best for measuring the radiant energy. This method is characterized by its nonselectivity and the good linearity of the readings, which accounts for its prevalence in connection with actinometric measurements of shortwave integral fluxes.

Grigor'ev and Fomichev [2] have developed a method of determining the optical coefficients that employs the Savinov-Yanishevskii thermoelectric actinometer as the radiant energy receiver. This method requires specimens more than 3 m^2 in area (diameter 2 m). Accordingly, there is a need for an instrument capable of handling much smaller specimens (down to 0.2 m^2).

If the receiver is arranged parallel to the irradiated surface, the irradiance at an elementary point of the receiver surface due to the reflected or transmitted radiation is expressed by the integral

$$E_k = \frac{kEh^2}{\pi}\int_0^{R_0}\int_0^{2\pi}\frac{RdRd\theta}{(R^2+h^2)^2}. \qquad (1)$$

After integration, the optical coefficient

$$k = \frac{E_k}{E}\left(1+\frac{h^2}{R_0^2}\right). \qquad (2)$$

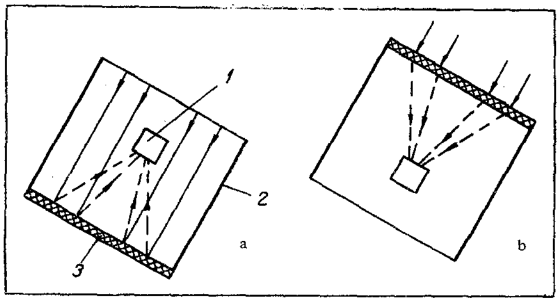
The values of E, E_k, h, and R_0 can easily be determined experimentally, and the reflectance $k = \rho$ and transmittance $k = \tau$ can be calculated from Eq. (2) for near-ideal scattering conditions (k = const as h/R_0 varies).

If the given dimensions of the specimen are 0.2 m^2 (diameter 0.5 m), to exclude screening in excess of 1% the projection of the receiver on the specimen should be not more than 0.05 m in diameter. Such a receiver was constructed around an Ångström compensation pyrheliometer [3], modified to permit continuous measurement of the direct and scattered radiation in relative units.

The arrangement for determining reflectance and transmittance is shown in the figure. The instrument consists of a receiver (pyrheliometer) housed in a protective cylinder. The diameter of the projection of the receiver on the specimen is 0.045 m.

To measure the scattered radiation, the sensitive element of an ordinary pyrheliometer was removed from its housing (with slits for transmitting parallel fluxes) and placed in a cylindrical sleeve without stops. The manganin-receiving surface of the pyrheliometer with the cold junction was protected from the incident radiation by an aluminum foil screen. In the screen there was a slot corresponding in shape and size to the other receiving surface with the hot junction of the thermocouple. The foil was arranged about 1 mm from the surface. To reduce the effect of convective air currents, the sensitive element was covered by a glass window. The glass has a transmittance of 90 ± ± 2% on the wavelength interval 0.3–2 μ within which the solar radiation is mainly concentrated [4]. The glass window was 2 mm away from the receiving surface, so that rays incident at angles close to 90° could reach that surface. To reduce heating, the projecting nuts which secured the thermocouple were covered with a ring of aluminum foil, from which they were insulated with several layers of BF-2 adhesive.

The longwave emission of the specimen due to radiative heating is almost completely cut off by the glass and does not reach the receiver. Hence, the emissivity of the test material does not have much effect on the accuracy of determination of the optical coefficients.



Arrangement of instrument for determining reflectance (a) and transmittance (b) (solid lines—incident flux, dashed lines—reflected and transmitted flux: 1) radiation receiver; 2) protective cylinder; 3) specimen.

The radiant fluxes were measured with a differential thermocouple, whose junctions were bonded to the exposed and protected receiving surfaces. As the measuring instrument, we used a GZS-47/5 mirror galvanometer with low internal resistance.

The receiver was designed to be displaced along the axis of the protective cylinder, which is necessary to permit experiments at different distances h between the receiver and the specimen.

The inside of the protective cylinder was covered with dull black paper or paint. The cylinder could be adjusted at any angle to the horizontal to bring the specimen into a position exactly at right angles to the sun's rays. Rotation in the horizontal plane was achieved by rotating the instrument as a whole.

Experiments were performed in clear cloudless weather using the solar radiation. It is also possible to use another source with a similar spectrum and a radiation density of about 800 W/m^2. Before each experiment the instrument is exposed to irradiation for 15–20 min to bring the receiver and the ambient medium into thermal equilibrium. The galvanometer is adjusted to zero with the receiver cover closed. A sight is used to aim the instrument at the sun and the solar radiation is checked with an albedometer.

After the cover has been removed, the number of galvanometer divisions corresponding to the direct radiation n is determined. The number of divisions corresponding to the reflected radiation n_0 is determined in the arrangement shown at a) in the figure. To determine the transmitted radiation n_t, the cylinder and the specimen are rotated through 180° (figure, b).

The reflectance ρ, transmittance τ, and absorptance α are calculated from formulas derived from (2):

$$\rho = \frac{n_0}{n}\left(1 + \frac{h^2}{R_0^2}\right), \tag{3}$$

$$\tau = \frac{n_t}{n}\left(1 + \frac{h^2}{R_0^2}\right), \tag{4}$$

$$\alpha = 1 - \rho - \tau. \tag{5}$$

Values of ρ and, hence, τ, determined at different values of h/R_0 under conditions approaching ideal scattering in the presence of reflection and transmission, should be constant.

As an experimental check on the reproducibility of the conditions necessary for the accurate determination of the optical coefficients of textiles we performed experiments (table) at various values of h (R_0 = 195 mm = const) on fabrics with different colors and structures.

Integral Optical Coefficients of Textiles (h/R_0 = 0.5–1.0 absolute error of measurements ±3%)

Cotton fabric	ρ	τ	α
Brown tricot, art. 688	0.17	0.01	0.82
Brown raincoat cloth, art. 610	0.17	0.02	0.81
White gingham, art. 150	0.55	0.12	0.33
Dark-gray gingham, art. 150	0.18	0.06	0.76
Calico, art. 52	0.56	0.33	0.11
White towel cloth, art. 1050	0.59	0.22	0.19

It was found that the optical coefficients ρ and τ of fabrics of different color and structure remain almost constant (±3%) in the range h/R_0 = 0.5–1, which indicates that the instrument is capable of reproducing conditions approaching ideal scattering.

The instrument developed can be used to determine with reasonable accuracy the integral optical coefficients of relatively small (0.2 m^2) textile specimens.

NOTATION

E is the irradiance; E_k is the reflected or transmitted irradiance; R_0 is the radius of the irradiated surface; R and θ are the polar coordinates of a point on the receiver surface; h is the distance from the irradiated surface to the plane of the receiver; k are the optical coefficients of the reflectance ρ, transmittance τ, and absorptance α.

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