METHOD OF SIMULTANEOUSLY MEASURING THE DOUBLE HEMISPHERICAL THERMAL RADIATION CHARACTERISTICS OF SCATTERING MATERIALS

S. G. II'yasov, V. V. Krasnikov, and E. P. Tyurev

Methods of measuring the hemispherical reflecting and transmitting powers of radiation-scattering materials, simultaneously or as a complex operation, on subjection to hemispherical irradiation are considered.

The calculation of radiant heat transfer is quite impossible unless the spectral and integrated thermal-radiation characteristics $R$, $T$, and $A$ of the irradiated materials, measured with due allowance for the scattering of the radiation, are known. The quantities $R$, $T$, and $A$ depend both on the state and properties of the material and on the spatial characteristics and spectral composition of the incident flow of radiation (i.e., the irradiation conditions). The majority of published experimental data regarding the spectral reflecting and transmitting powers $R_\lambda$ and $T_\lambda$ of radiation-scattering materials have been obtained for irradiation by a radiant flux incident at a small angle $\theta = 5-10^\circ$ [1-4]. These values, i.e., the directional-hemispherical coefficients $R_\lambda(\theta; 2\pi)$ and $T_\lambda(\theta; 2\pi)$, may only be used in calculating radiant transfer corresponding to the actual irradiation conditions.

The authors therefore studied the manner in which $R_\lambda(\theta; 2\pi)$ and $R_\lambda(\theta; 2\pi)$ varied with the angle of incidence $\theta$ experimentally for layers of various scattering materials (Fig. 1a), such as 0.52 mm polyethylene (curves 1), 0.09 paper (curves 2), etc; the results showed that $R_\lambda$ increased and $T_\lambda$ diminished with increasing angle of incidence. Hence the double-hemispherical reflecting power $R_\lambda(2\pi; 2\pi)$ will be greater than the directional-hemispherical value $R_\lambda(\theta; 2\pi)$, while $T_\lambda(2\pi; 2\pi)$ will be smaller than $T_\lambda(\theta; 2\pi)$ measured for normal irradiation by a parallel flux of radiation.

The relationships shown in Fig. 1b for the double-hemispherical and directional-hemispherical thermal-radiation characteristics of polyethylene, paper, and raw potato support the foregoing considerations.

In any practical thermal-radiation installations (furnaces and closed chambers) irradiation by a diffuse or mixed (diffuse + directional) radiation flux is the rule. In view of this it is important to measure the double-hemispherical parameters $R_\lambda(2\pi; 2\pi)$ and $T_\lambda(2\pi; 2\pi)$ of the materials on subjection to a diffuse flow of radiation.

A direct method of measuring the double-hemispherical parameters $R_\lambda(2\pi; 2\pi)$ and $T_\lambda(2\pi; 2\pi)$ or radiation-scattering materials was first proposed by Duntley [7]. In this method the hemispherical irradiation of the sample and the measurement of its hemispherical reflecting and transmitting powers are

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\lambda & 0.5 & 1.0 & 2.0 & 10.0 & 15.0 & 25.0 \\
\hline
R_\lambda(\theta; 2\pi) & 0.864 & 0.916 & 0.969 & 0.973 & 0.974 & 0.975 \\
\hline
\end{array}
\]


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carried out with the aid of two identical integrating spheres containing three apertures. The advantage of this method lies in the possibility of carrying out absolute measurements of $R_k(2\pi; 2\pi)$ and $T_\Lambda(2\pi; 2\pi)$; however, it imposes strict requirements upon the accuracy of photometric measurement, covers only a limited spectral range 0.40-0.75 $\mu$m, and involves a complex measuring technique [7].

A simpler method of measuring the double-hemispherical transmitting power $T_\Lambda(2\pi; 2\pi)$ was described and an attachment to the SF-4A spectrophotometer, offering a spectral range of 0.4-1.4 $\mu$m, was proposed by the authors in an earlier paper [3]. In order to obtain hemispherical irradiation of the sample this system uses an MS-14 reflection standard and a specular ellipsoid, while for measuring the hemispherical radiation passing through the sample a receiver with a large receiving area is employed (an FESS-U10 photocell).

For measuring the double-hemispherical reflecting power $R_\Lambda(2\pi; 2\pi)$ in the infrared part of the spectrum 1-38 $\mu$m, Sherrell and Sharhrokhi [8] developed a spectrophotometer attachment with a CsBr prism in the form of an integrating sphere. The surfaces of the sphere and reflecting standard are coated with gold having a diffuse reflecting power $R_\Lambda \approx 0.35$. The value of $R_\Lambda(2\pi; 2\pi)$ is measured relative to the standard. This method also makes severe demands upon the accuracy of the photometric measurements. The accuracy of the measurements is less than $\pm 2\%$ [8].

Experimental-analytical methods of determining the double-hemispherical parameters $R_\Lambda(2\pi; 2\pi)$ and $T_\Lambda(2\pi; 2\pi)$ are based on an experimental determination of the hemispherical brightness coefficients (radiance) $\rho_\Lambda(2\pi; \theta_R, \varphi_R)$ and $\tau_\Lambda(2\pi; \theta_T, \varphi_T)$ or the reflection coefficients $R_\Lambda(\theta; \varphi; 2\pi)$ and $T_\Lambda(\theta; \varphi; 2\pi)$ for various angles of observation $\theta_R, \varphi_R$ and $\theta_T, \varphi_T$ or angles of incidence of the radiant flux $\theta, \varphi$ and the analytical relationships between these [2, 3, 5]:

$$R_\Lambda(2\pi; 2\pi) = \frac{1}{\pi} \int \rho_\Lambda(2\pi; \theta_R; \varphi_R) \cos \theta_R d\theta_R,$$

where $d\Omega_R = \cos \theta_R d\theta_R d\varphi_R$.

### Table 2. Spectral Reflection Indicatrixes of the Sphere Coating for Normal Irradiation

<table>
<thead>
<tr>
<th>Wave-length, $\mu$m</th>
<th>Reflection angle, deg</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.292</td>
<td>0.295</td>
<td>0.366</td>
<td>0.450</td>
<td>0.530</td>
<td>0.610</td>
<td>0.690</td>
<td>0.770</td>
<td>0.860</td>
</tr>
<tr>
<td>2.0</td>
<td>0.293</td>
<td>0.363</td>
<td>0.450</td>
<td>0.530</td>
<td>0.610</td>
<td>0.690</td>
<td>0.770</td>
<td>0.860</td>
<td>0.950</td>
</tr>
<tr>
<td>15.0</td>
<td>0.361</td>
<td>0.292</td>
<td>0.295</td>
<td>0.366</td>
<td>0.450</td>
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</tr>
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