AN INVESTIGATION OF THE EMISSIVITY OF BUILDING MATERIALS

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This paper gives the results of measurements of the spectral emissivity of concretes, soil concretes, gypsum, and plaster in the wavelength region 2.5–25.0 μ. These measurements are used to calculate the integral emissivities of these materials.

The progressive radiative method of heating is being more and more widely adopted in the heat-treatment plants of the building materials industry. The design of such plants necessitates a knowledge of the optical properties (primarily the emissivity ε) of the materials to be treated.

Most authors who have carried out investigations of the emissivity of building materials [1–3] have proceeded from the assumption that these materials emit and absorb radiation like gray bodies. However, the change in the integral reflecting power in relation to the temperature of the radiation source [4, 9, 10] indicates that most materials have selective optical properties.

The shortcomings of methods of determining the integral optical characteristics of materials have already been mentioned in several papers [5, 6]. Another point that should be noted is that the direct measurement of integral characteristics does not reveal the wavelength range in which the material absorbs best and, hence, the best temperature of the infrared radiator for treatment of the particular material.

In [13] data relating to the spectral distribution of the emissivity of building materials were obtained by measuring their reflection coefficients R_λ. Since these materials are practically opaque,

$$\varepsilon_\lambda = 1 - R_\lambda. \tag{1}$$

A fault of this method is that the radiation detector receives not only the reflected energy, but also the characteristic emission of the investigated specimen, and this must lead to some error in the measurements. Since building materials contain a large amount of SiO_4 or SO_4 groups, which possess the property that the reflection and absorption coefficients vary sinusoidally with the orientation of the plate relative to the incident radiation (the variations reach 40% [7]), the results of the measurements vary very considerably with change in the angle of inclination of the specimen. Moreover, in [13] the spectral range of the measurements was very small (0.5–9.0 μ). Hence, interpolation of the obtained data to a radiation source with a temperature of 300°K is not valid, since at 700° K more than 40% of the emitted energy is outside this range. These difficulties can be overcome by using an integrating reflecting hemisphere, but in the case of diffuse or mixed reflection it is impossible to make an accurate allowance for loss of reflected radiation through the hole in the hemisphere or for the screening effect of the radiation detector holder [9].

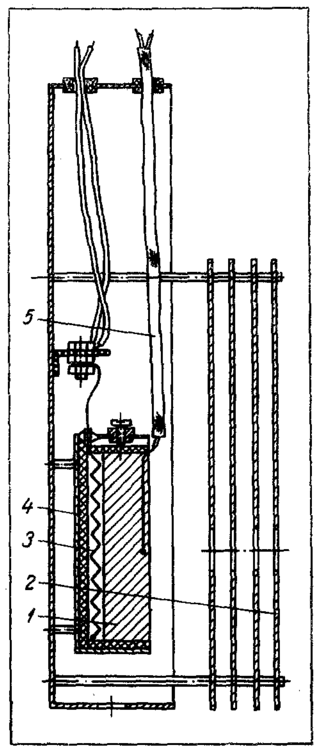

Fig. 1. Holder and specimen: 1) specimen; 2) screens; 3) heater; 4) heat insulation; 5) chromel-copel thermocouple.

The above considerations induced us to investigate the measurement of the spectral emissivity of building materials by comparing the intensity of the emission of the investigated material (I_λ) and that of an ideal black body (I_{λ_0}):

$$\varepsilon_\lambda = I_\lambda / I_{\lambda_0}. \tag{2}$$

This method has been successfully used for measurements of the emissivity of metals [15].

The measurements were made on an IKS-12 infrared spectrograph. The sensitivity and resolution of the instrument were greatly increased by using a bolometer as the radiation detector and a special amplifier [11]. The output signal of the amplifier was recorded on the graph paper of an EPP-09 potentiometer. Rock salt lenses were used in the wavelength range 2.5–15 μ and potassium bromide lenses in the 15–25 μ range.

The materials selected for investigation were ordinary heavy concrete, keramzit concrete, soil concrete, gypsum, and lime plaster:

Specimen	Composition of specimen
Concrete	Cement + sand + rubble + water 1 : 1.9 : 3.9 : 0.48
Soil concrete	Slag + sand + 20% soda potash solution 1 : 1 : 0.4
Soil concrete	Slag + sand + 20% caustic soda solution 1 : 1 : 0.36
Gypsum	Building gypsum
Keramzit concrete	Cement + sand + keramzit + water 1 : 2 : 1 : 0.4
Plaster	Milk of lime + sand 1 : 2

Specimens of dimensions 45 × 50 × 12 mm were prepared from these materials. In the preparation of the specimens chromel-copel thermocouples of 0.5-mm wire were attached to the surface of the specimens.

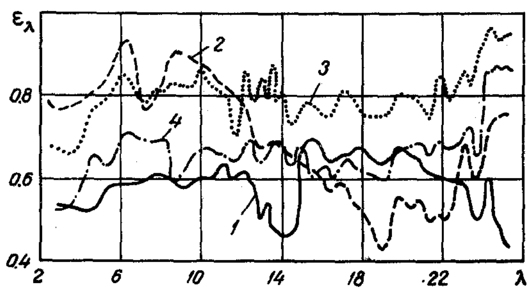

Fig. 2. Spectral distribution of emissivity: 1) for concrete and keramzit concrete; 2) soil concretes; 3) gypsum; 4) plaster.

The specimens were placed in a special holder with a heater (Fig. 1). The temperature of the specimens during the experiments was monitored by a KP-59 potentiometer. The temperature was regulated by changing the voltage on the heater. The emission of the specimen was diaphragmed by a three-layer screen of anodized aluminum. The diameter of the aperture (8 mm) in the screen was equal to that of the ideal black body.

In the experiments we used an ideal black body with a diaphragm cooled with flowing water. The design of the model was similar to that described in [8].

The results of the experiments (Fig. 2) showed that all the investigated materials emit selectively. The selective nature of the emission spectrum of building materials can be attributed to the presence of silicates containing the SiO_4 group. The authors of [9, 10] came to a similar conclusion.

The concrete and keramzit concrete specimens had the same spectral characteristic. This can be attributed to the fact that the emission of the bulk of the material is absorbed in the very thin outer layer and in both specimens the thin outer layer consists of cement solution. A specimen of pure cement solution will obviously have the same spectral characteristic. A similar effect was observed in the specimens of different soil concretes.

The first experiments showed that changes in the temperature of the specimens in the range 50–100° C did not produce any appreciable change in their spectral characteristics. Hence, further experiments were conducted at the maximum possible temperatures for the particular specimens (mainly at 100° C), since this enabled us to reduce the amplification factor and thus reduce the effect of extraneous radiation sources.

From the obtained spectral emissivities we could calculate the integral emissivities for different temperatures of an ideal black radiation source.

The amount of energy emitted by the specimen is

$$\varepsilon\sigma T^4 = \int_0^\infty \varepsilon_\lambda I_{\lambda 0}\, d\lambda. \tag{3}$$

From formula (3) we find

$$\varepsilon = \int_0^\infty \varepsilon_\lambda \left(\frac{I_{\lambda 0}}{\sigma T^5}\right) d(\lambda T). \tag{4}$$

The value of the integral $\int_0^{\lambda T} \frac{I_{\lambda 0}}{\sigma T^5}\, d(\lambda T)$ from 0 to λT is shown in the graph in Fig. 3, plotted from the data of [14]. These values represent the part of the energy of an ideal emitter between 0 and λ, μ, for temperature T, °K.

Since the values of ε_λ cannot be determined in the whole range of integration, we have to evaluate the error in the calculations. For instance, for a temperature of 800° K, less than 1.5% of the total radiation energy lies below 2.5 μ (λT = 2000). Approximately 4% of the energy lies above 25 μ (λT = 20 000). The total error does not exceed 5.5%.

To reduce this error we assume that the emissivity of the specimen from 2.5 μ to 0 is equal to the emissivity in the region 2.5–3.0 μ, and from 25 μ to infinity is equal to the emissivity in the region 24–25 μ. However, since the specimens cannot be absolutely white at the ends of the interval, the actual error of the calculations will be well below the cited figure.

Similarly, for 400° K the error will be less than 17%, for 600° K less than 6.5%, for 1000° K less than 9%, and for 1200° K less than 12%.

The results of calculations of the integral emissivity of the investigated materials for temperatures of the ideal black radiation source from 400° to 1200° K are shown in Fig. 4. This is the temperature range of operation of the common industrial infrared radiation sources (for instance, TEN and gas radiators have a temperature of about 450–950° C).

An analysis of the results of the investigation of the optical properties of several building materials showed that:

1. Building materials—concretes, soil concretes, gypsum, and plaster—have distinctly selective optical properties in the wavelength range 2.5–25.0 μ.

2. The optical properties of these materials do not depend on the temperature of the material itself in the range 50–100° C, but depend on the temperature of the radiation source.

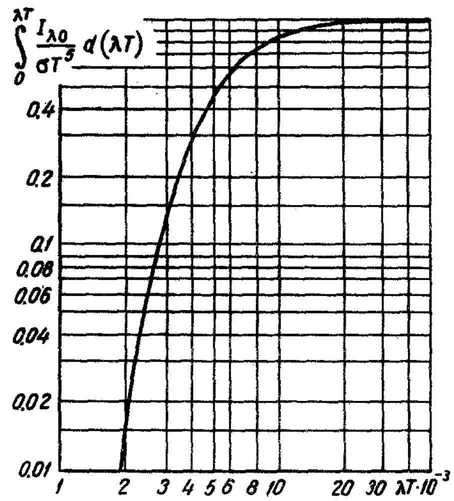

Fig. 3. Graph of function $\int_0^{\lambda T} \frac{I_{\lambda_0}}{\sigma T^5} d(\lambda T) = f(\lambda T)$.

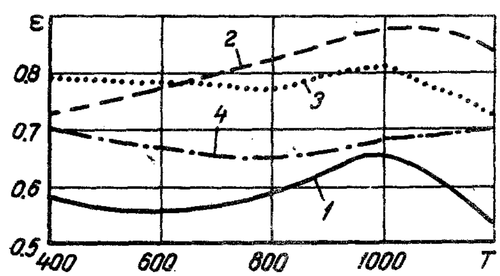

Fig. 4. Integral emissivity as a function of temperature of ideal black radiation source: 1) for concrete and keramzit concrete; 2) soil concrete; 3) gypsum; 4) plaster.

3. The maximum values of the integral emissivity of building materials are attained at a source temperature of 900–1100° K and, hence, infrared radiators operating at such temperatures are best for heat treatment of these materials.

NOTATION

ε is the integral emissivity; ε_λ is the monochromatic emissivity at wavelength λ; R_λ is the monochromatic reflecting power at wavelength λ; I_λ is the intensity of emission of investigated material at wavelength λ; I_{λ_0} is the intensity of emission of ideal black body; σ is the Stefan-Boltzmann constant; T is the temperature in ° K.

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