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ENERGY CHARACTERISTICS OF A HIGH-TEMPERATURE IR RADIATOR

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Results are presented on the temperatures of the heated body and fused-silica envelope for a high-temperature IR emitter of new design based on a halogen filament lamp.

Infrared (IR) heating is increasingly used in technology. IR heating often not only accelerates the process considerably but also provides higher performance. In particular, specially designed devices are used in the electronics industry as sources of high-temperature radiation for IR heating, which have been called IR modules. Such devices were first described in [1].

The successful use of IR modules has required detailed theoretical and experimental studies on the thermophysical parameters of these in order to indicate the potential of such devices and the scope for making new designs. A model has been given [2] for calculating the heat transfer in an IR module, and the integral and spectral densities of the useful radiation flux have been calculated, while the temperatures of the fused-silica envelope and heated body have been determined. The calculated values were in satisfactory agreement with published data. However, comparison of these results was possible only on extrapolating the energy characteristics of the IR module to the corresponding values for a single halogen filament lamp (HFL). A more rigorous check on the numerical results of [2] is given here from an experimental study of IR module characteristics.

The most general form of IR module consists of a heated body (tunsten spiral 1, Fig. 1) enclosed in a gas-filled cylindrical silica envelope 2, which is enclosed in the hollow metal body 3 within the planar angle $2\pi - \beta$. The body has a reflecting coating of the maximum possible reflectivity on the side facing the silica envelope. The body thus also acts as a reflector. The cooling liquid 4 circulates within the body. Various designs of module are possible in accordance with the value of $2\pi - \beta$ and the air gap between the envelope and the reflector.

This IR module has some obvious advantages (simple design, compactness, and safety), and it also substantially increases the useful radiation flux in a given direction, which is attained by fairly simple means and without the use of expensive focusing reflectors. Numerical calculations [2] show that the temperature of the spiral is increased by 80-200°K in accordance with the angle β.

This effect occurs because the cylindrical heated body is at the focus of the cylindrical reflector. The radiation emitted by the body within the angle $2\pi - \beta$ is returned by the reflector and is partially absorbed (the absorptivity of a tungsten spiral is about 0.4 [3]). As a result, there is self-irradiation, so the temperature rises by ΔT, which leads to the emission of a more powerful useful flux within the given angle β (increase by 25-30%).

The second major advantage of the IR module is that the water-cooled reflector substantially reduces the temperature of the silica envelope, which is important when the module is used in closed IR heating systems.

Particular interest attaches to comparing the numerical calculations with measurements on the temperature of the heated body in the IR module and that in an identical free HFL, as well as to correct temperature measurement for the silica envelope.

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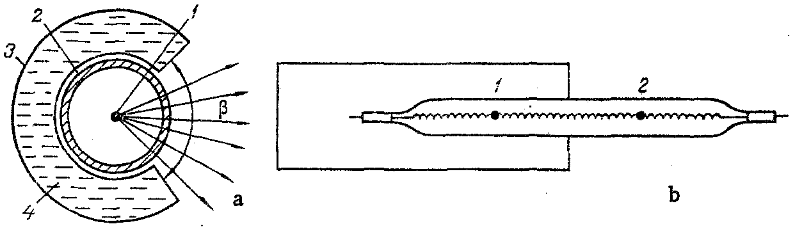

Fig. 1. Cross section of the IR radiator (a): 1) heated body; 2) silica envelope; 3) reflector body; 4) cooling liquid; also disposition of emitter filament and body in the determination of the temperature difference ΔT between points 1 and 2 (b).

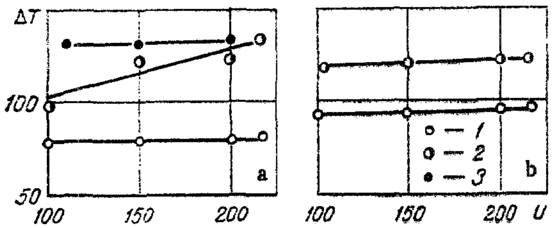

Fig. 2. Voltage dependence of the temperature difference ΔT between points on the filament 1 and 2: a) polished brass reflector; b) gold-plated one; 1) outside of spiral turn; 2) inside of spiral turn; 3) numerical calculations [2]; T in °K and U in V.

The temperature of the heated body was measured with a VIMP-015 M brightness pyrometer with an effective wavelength of 0.66 μm. The minimum size of the object is 0.1 mm. The following method was used to eliminate errors associated with possible changes in the heating conditions, differences in resistance in the heated bodies, and the time separation in measuring the two temperatures.

Figure 1b shows that the radiator is moved halfway out of the body, and the brightness temperature T_b is measured at two symmetrical points 1 and 2. Thus, one obtains the temperature difference ΔT for the same body at two characteristic points. One of these is under conditions of self-irradiation and the other is under conditions completely eliminating this effect.

Parts a and b of Fig. 2 show the results, where curve 1 represents the temperature difference between points 1 and 2 with the pyrometer sighted on the outside of a spiral turn, while curve 2 is the same with the instrument sighted on the inside of a turn. For comparison, curve 3 of Fig. 2a gives numerical calculations on the temperatures of the spirals for a single free HFL and for the IR module with $\beta = 2\pi \cdot 0.4$, which show good agreement between the experimental and theoretical results.

Temperature distributions were also obtained for the longitudinal axis of the heated body for reflectors made either of polished brass or with gold plating.

Figure 3 shows T_b for the two types of reflector in relation to the longitudinal coordinate, which indicates that the temperature distribution is uniform. The lower T_b at the point with coordinate 4-5 mm is due to shadowing by the silica socket. There are only slight differences in T_b for the gold-plated and brass reflectors, which is due to the good cooling of the reflector, which means that the reflectivity is stable although the thermal conditions are severe.

There is considerable difficulty in measuring the temperature of the transparent envelope as it is exposed to the high-intensity radiation flux. Thermocouples give considerable errors, since the measured temperature is dependent on the emissivity of the hot junction. The literature carries temperatures for the envelopes of HFL [3], but without any statement of how they were measured.

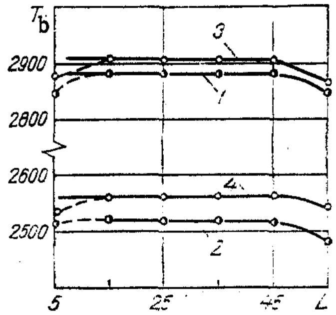

Fig. 3

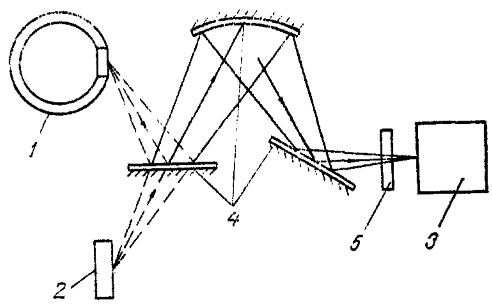

Fig. 4

Fig. 3. Distributions of brightness temperature T_b (°K) in a filament along the half-length. Reflectors: 1, 2) polished brass; 3, 4) gold plated; 1, 3) U = 220 V; 2, 4) U = 150 V; L in mm.

Fig. 4. Apparatus for measuring the temperature of the silica envelope by a spectral method: 1) BB model; 2) object; 3) monochromator from single-beam IR spectrophotometer; 4) optical attachment; 5) dispersion-interference filter.

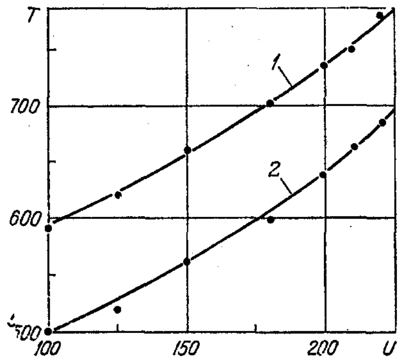

Fig. 5. Dependence of the true temperature T of the silica envelope on supply voltage: 1) for a free HFL; 2) for an HFL in a water-cooled reflector.

We have devised an optical method of measuring the true temperature of the silica envelope in the IR module. The apparatus (Fig. 4) consists of the blackbody (BB) model 1, the object 2, the monochromator 3 from a single-beam IR spectrophotometer type IKS-21, and the optical attachment 4, which enables one to image in turn the radiating cavity of the BB and the object (silica envelope) on the monochromator slit. The BB temperature is stabilized and is measured with a CC thermocouple.

The intensity provided by the BB and that from the object were recorded at λ = 6 μm. The working wavelength was chosen in the region of complete opacity for the fused silica envelope [4]. This completely eliminated any effect on the results from the direct radiation from the filament. The IR intensity at the peak (at λ = 1 μm) exceeds that at λ = 6 μm by several orders of magnitude, so it was necessary to eliminate scattered short-wave radiation. This was handled by placing a narrow-band dispersion-interference IR filter in front of the entrance slit having an effective wavelength λ = 6 μm and a half-width for the transmission band $\Delta\lambda$ = 0.18 μm.

With the object imaged on the monochromator slit, the signal at the pen recorder is

$$S_1 = KI(\lambda,\ T_0) = K\varepsilon_{\lambda_0}\cdot 2hc^2 \frac{\lambda^{-5}}{\exp\left[\dfrac{hc}{kT_0\lambda}\right] - 1}, \tag{1}$$

where ε_{λ_0} is the monochromatic emissivity of the envelope material, whose true temperature is T_0, and $I(\lambda, T_0)$ is the spectral density of the equilibrium radiation flux at T_0. Correspondingly, the signal S_2 produced by the BB under the same conditions is

$$S_2 = K2hc^2 \frac{\lambda^{-5}}{\exp\left[\frac{hc}{kT_{bb}\lambda}\right] - 1}. \quad (2)$$

Then T_0 is given by

$$\frac{S_2}{S_1} = \varepsilon_{\lambda_0} \frac{\exp\left[\frac{hc}{kT_0\lambda}\right] - 1}{\exp\left[\frac{hc}{kT_{bb}\lambda}\right] - 1}. \quad (3)$$

The measurement procedure was as follows. The BB temperature is varied to produce equal signals from the BB and object. The BB temperature is then measured, which gives the brightness temperature of the envelope T_{bo}. Then T_0 is calculated from published data on the spectral emissivity of fused silica.

A second series of measurements was made on the BB with recording of the S_1/S_2 ratio. Then T_0 was calculated from (3).

The systematic relative error in determining the true temperature by this method was 2.5% for an absolute error in determining the BB temperature of $\Delta T = 5°K$, error in wavelength determination $\Delta\lambda = 0.01$ μm, and error in determining the emissivity $\Delta\varepsilon_\lambda = 0.01$ at $\lambda = 6$ μm.

Figure 5 gives temperatures for the silica envelope in the IR module and for free HFL. The water-cooled reflector in thermal contact with the envelope effectively reduces the temperature of the free part. The temperature reduction is 100°K or more, which is an important advantage of these IR modules, since it enables one to raise the upper temperature limit of the IR heating system considerably by the use of new high-temperature IR emitters.

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