DISTRIBUTION OF THE IRRADIANCE OF SOME "LIGHT" INFRARED SOURCES

V. P. Dushchenko, I. M. Kucheruk, P. V. Berezhnoi, and A. F. Bulyandra

Inzhenerno-Fizicheskii Zhurnal, Vol. 11, No. 3, pp. 296–300, 1966

UDC 536.3:535.34+621.035.211–15

This paper gives the results of an experimental investigation of the distribution of the irradiance of some of the most widely used "light" infrared sources. Their spectral characteristics are also given.

"Light" IR sources are used in industrial radiant driers. Some of the parameters of these sources are given in [1–7]. The calculation and design of driers must provide for uniform heating of the material to be dried. This necessitates an investigation of the distribution of the irradiance of "light" IR sources.

Instruments with sensitive thermoelectric detectors of radiant energy, such as the Boiko [2] and TsKTI [8] radiometers, the Yanishevskii balancemeter and pyranometer [9], etc., can be used for this purpose. We used the mass-produced M-10 balancemeter in conjunction with a GSA-1 galvanometer and, in addition, a special device employing the heat-flux gauge designed at the Institute of Technical Thermophysics, AS UkrSSR [10]. The receiving surface of the fast-response balancemeter is nonselective. We determined the conversion factor a of the balancemeter by comparing its readings with those of a standard actinometer, which was calibrated in turn against the readings of a standard instrument—a compensation pyrheliometer. The irradiance E (W/m^2) was calculated from the formula $E = na$. The conversion factor was determined from the formula

$$a = a_0\left(1 + \frac{R_{b00}}{R_g + R_b}\right). \tag{1}$$

In our case $a_0 = 12.7\ W/m^2 \cdot div$. The ITT heat-flux gauge was calibrated against a complete emitter standard. In the measurement of high irradiances the "cold" junctions of the thermopile of the balancemeter and the heat-flux gauge were heated during the measurement and this led to underestimates of the irradiance. To prevent this we used a thermostat to keep the "cold" junctions of the thermopile at a constant temperature.

To record the distribution of irradiance we mounted the IR sources over a coordinate grid with squares of the same size as the receiving area of the balancemeter. The irradiance values given in Figs. 1 and 2 and in Tables 1 and 2 are the mean values measured in four mutually perpendicular directions at the same distance l from the axis of symmetry of the source. The reason for this is that "light" IR sources produce an asymmetric distribution of irradiance. For instance, for the same l and other conditions equal, the irradiances were different and varied for sources of the ZS type and the VEB factory (G. D. R.) type in the range ±20% for h = 0.1 m, and ±10% for h = 0.5 m. For the sources produced by the Elprom factory (Bulgaria) the variation was ±10% for h = 0.1 m and ±5% for h = 0.5 m. These fluctuations can be attributed to the variable shape of the incandescent element and its position relative to the reflector. Hence for these heights the "light" IR sources cannot be regarded as point sources.

The results of the investigation are given in Fig. 1 and in Tables 1 and 2.

An analysis of the data obtained shows that the irradiances produced by the sources were not directly related to their power consumption. The most efficient in this respect were the ZS sources. For instance, for a ZS-2 lamp with $l = 0$ and $h = 0.3$ m, $E/P = 10.6\ 1/m^2$, and for the Elprom lamp (P = 250 W) $E/P = 2.1\ 1/m^2$. The ratio E/P for each source varied in different ways with change in h. For instance, with change of h from 0.3 to 0.1 m, E/P for the ZS-2 lamp increased by a factor of 3.6, and for an Elprom lamp with the same power consumption E/P increased by a factor of 8. Hence, it is better to use Elprom lamps when h is small. For the same heights the Elprom lamps ensured sufficient uniformity of irradiance. For similar reasons ZS lamps are better for use when h is large. We should also mention that uniform irradiance is produced by ZS lamps for h ≥ 0.5 m, and by the Elprom and VEB lamps for h ≥ 0.4 m. This was accompanied by a considerable reduction of the irradiance. For instance, for ZS lamps with $l = 0$ and $h = 0.5$ m E was 10–12% of E for $l = 0$ and $h = 0.1$ m. The corresponding figure for the Elprom and VEB lamps was 3–7%.

Figure 2 shows that for $l = 0$ and $h = 0.1$ m the irradiance produced by this source was one third of that of the ZS-3 lamp for the same l and h, despite the fact that their power consumption was twice as great. When a cylindrical reflector was used with this lamp E was increased by a factor of 3 for $l = 0$ and $h = 0.1$ m and by a factor of 7 for $l = 0$ and $h = 0.7$ m. The small size of these lamps means that greater uniform irradiances can be obtained from the same area than in the case of ZS sources.

Figure 1 also shows the relationships $E = f(U)$ for $l = 0$ and $h = 0.3$ m, which are linear. These relationships can be conveniently and economically applied in the heat processing of materials, particularly thermally unstable materials, instead of the laborious operation of regulating the distance from the sources to the material.

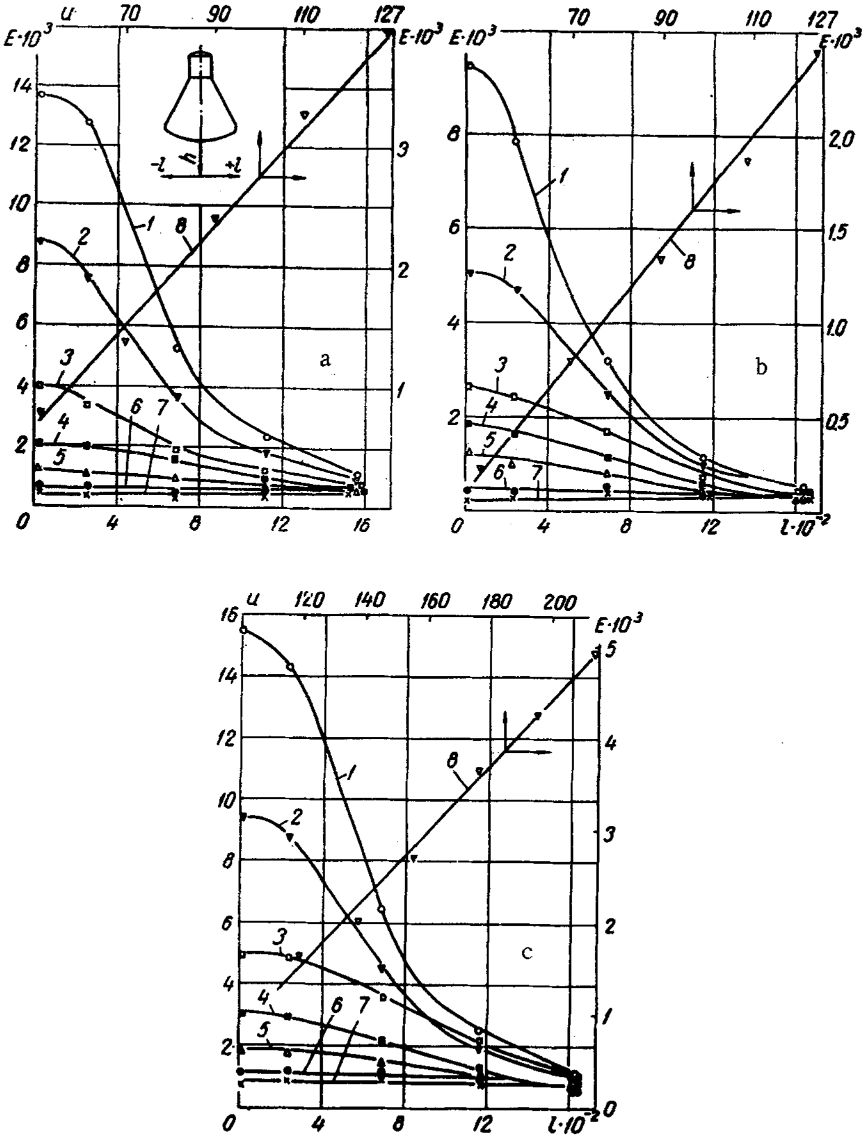

Fig. 1. Distribution of irradiance E (W/m^2) of IR sources (a—ZS-1; b—ZS-2; c—ZS-3) for different heights h of: 1) 0.1 m; 2) 0.2; 3) 0.3; 4) 0.4; 5) 0.5; 6) 0.6; 7) 0.7; and 8) different supply voltages U (volts) for h = 0.3 m

Table 1. Distribution of Irradiance of IR Sources

Source	$E \cdot 10^2$, W/m²							
	$l \cdot 10^{-2}$ m / h (m)	0	2.3	7.0	11.7	16.4	21.0	25.3
Elprom lamp (220 V, 375 W)	0.1	120	100	40.5	15.4	8.4	4.2	2.8
	0.2	50	47.6	34.2	14.0	7.6	5.0	3.8
	0.3	23	24.3	20.7	12.8	7.8	4.7	3.4
	0.4	12.6	12.9	12.7	10.0	7.0	4.5	3.3
	0.5	8.4	8.4	8.6	7.4	6.0	4.4	3.4
	0.6	5.6	5.6	5.7	5.3	4.7	4.0	3.0
	0.7	4.0	4.0	4.0	4.0	3.7	3.3	2.8
Elprom lamp (220 V, 250 W)	0.1	40.6	41.2	28.0	12.7	7.6	4.0	2.5
	0.2	12.6	12.8	13.8	10.5	7.4	4.4	2.8
	0.3	5.3	6.0	6.7	6.3	5.7	4.7	3.2
	0.4	2.4	2.3	2.3	2.5	2.4	2.3	1.8
	0.5	1.5	1.6	1.5	1.6	1.6	1.6	1.3
	0.6	1.3	1.3	1.3	1.3	1.4	1.4	1.4
	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9
VEB lamp (220 V, 250 W)	0.1	64.2	58.4	28.6	10.0	5.0	2.9	2.2
	0.2	14.5	15.4	17.3	11.4	5.8	2.8	1.8
	0.3	6.0	6.0	7.6	8.5	6.2	3.4	2.3
	0.4	3.3	3.3	3.7	4.5	5.2	4.0	2.4
	0.5	2.1	2.1	2.3	2.8	3.0	3.3	2.7
	0.6	1.4	1.3	1.5	1.8	1.9	2.0	2.3
	0.7	1.0	1.0	1.1	1.3	1.4	1.6	1.6

Table 2. Irradiance of IR Sources for $l = 0$ and $h = 0.3$ m

Source	$E \cdot 10^2$, W/m² for different U, v				
	200	180	160	140	120
Elprom lamp (220 V, 375 W)	19.7	16.6	13.2	10.4	7.5
Elprom Lamp (220 V, 250 W)	3.2	2.8	2.2	1.5	1.2
VEB lamp (220 V, 250 W)	5.4	4.3	3.4	2.5	1.9

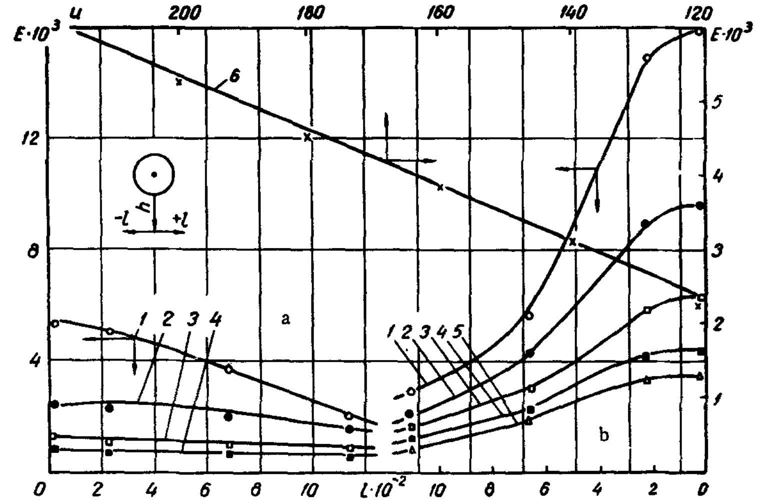

Fig. 2. Irradiance E (W/m^2) of NIK-220 × 1000$_{tr}$ IR lamp a) without a reflector; b) with a reflector; for different heights h of: 1) 0.1 m; 2) 0.2; 3) 0.3; 4) 0.4; 5) 0.5; and 6) different supply voltages U (volts) with reflector for h = 0.3 m.

The experimental values of the irradiance can be represented analytically by an empirical formula of the form

$$E = E_0 \exp\left[-bl^c\right]. \tag{2}$$

For instance, for a ZS-3 lamp with h = 0.3 m, b = = 0.066, c = 1.238, and for h = 0.5 m, b = 0.006, c = = 1.761. The irradiance values calculated from these formulas differed from the experimentally obtained values by ±2–7%, which is quite satisfactory, since deviations of irradiance for different directions were ±20% of the mean value.

The scientifically based heat processing of materials requires, in addition to uniform irradiance, matching of the spectral characteristics of the lamps with the optical properties of the materials [11]. We obtained the spectral characteristics of the above "light" IR sources on a IKS-12 instrument. For the nominal voltages the maximum of the emission was at wavelength $\lambda = 1.3\mu$. In this case approximately 75% of the irradiated energy lay in the wavelength range from 1 to 2 μ. Hence, the investigated "light" IR sources can be effectively used for the heat processing of materials which have maximum absorption in this wavelength range.

NOTATION

n denotes number of divisions on galvanometer scale; a_0 is the conversion factor of balancemeter with galvanometer without external booster resistor; R_{b00} and R_g, R_b are external booster resistor and total internal resistance of galvanometer, thermopile, and balancemeter; h is the height of suspension of source over surface of coordinate grid; p is the power consumption of source; u is the source supply voltage; b and c are constants.

REFERENCES

1. V. Z. Gurevich, Electrical Infrared Emitters [in Russian], Gosenergoizdat, 1963.
2. P. D. Lebedev, Drying by Infrared Rays [in Russian], Gosenergoizdat, 1955.
3. P. D. Lebedev, Calculation and Design of Drying Devices [in Russian], Gosenergoizdat, 1963.
4. R. Borkhert and V. Yubits, Technique of Infrared Heating [in Russian], Gosenergoizdat, 1963.
5. M. Déribéré, Les applications pratiques des rayons infrarouges [Russian translation], Gosenergoizdat, 1959.
6. V. Z. Gurevich, Vestnik elektropromyshlennosti, no. 9, 1961.
7. M. V. Tirkel'taub, Svetotekhnika, no. 8, 1962.
8. A. I. Chernogolov, Zavodskaya laboratoriya, no. 2, 1949.
9. Yu. D. Yanishevskii, Actinometric Instruments and Methods of Observation [in Russian], Gidrometeoizdat, 1957.
10. O. A. Gerashchenko and V. G. Fedorov, Techniques of Heat-Engineering Experiments [in Russian], Izd. Naukova Dumka, Kiev, 1964.
11. A. S. Ginzburg, V. V. Krasnikov, and N. G. Selyukov, IFZh [Journal of Engineering Physics], 8, no. 6, 1965.

13 April 1966 Gor'kii Pedagogic Institute, Kiev