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RADIATION CHARACTERISTICS OF GAS INFRARED HEATERS IN RADIANT HEATING SYSTEMS

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UDC 536.3

Results of an experimental study of the radiation characteristics of commercial models of gas infrared heaters are presented. An analytic expression is obtained for the distribution of irradiance over a flat object at various distances from the heater.

Engineering methods for the design of radiant heating systems which are used in construction, petrochemistry, communal economy, and other fields are based on such radiation characteristics as radiation surface density, emissivity of heat-releasing surfaces, and radiant component of heat emission (radiant efficiency).

The characteristics listed are properties of the IR heater materials and depend on its mode of operation. As far as absorptive and reflective capabilities are concerned, they are

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functionals and their effect on heat exchange is insignificant because of the small size of heater surfaces in comparison with the surfaces of room enclosures.

An analysis of theoretical and experimental papers in this field provides a basis for the assertion that the method of direct instrumental measurements is the fundamental approach to solution of the problem in view of the limitations on the theoretical apparatus for the determination of the radiation characteristics of solids [1].

Thus the irradiance field was determined [2] for electric IR heaters used in drying technology; such studies were made for gas IR heaters [3, 4], but only individual heater elements were investigated.

The emissivity of molybdenum tubes has been determined [5]. Black and Schoenhals [6] made an experimental study of the emissive characteristics of a V-groove cavity which structurally resembles the channels in the head of a gas IR heater but which differs from them in thermal mode and operating conditions.

On the whole, one can state that the radiation characteristics of gas IR heaters have been poorly studied and the values of some of them vary from 30 to 70% [4].

The purpose of this work was to obtain an analytic relationship for the magnitude of the irradiance of a flat surface and also to study the emissivity and radiant efficiency of commercial models of gas IR heaters, the basic design and structural modifications of which are described in [7].

The method of study was the following. The heating was installed in a scale model of a one-story industrial building in the form of a room unit of reinforced concrete 4.5 × 3.0 × 2.5 m in size. For heights greater than 3 m, measurements were made in a shop area.

Scale-model simulation was based on the equalities of temperature, emissivity, and specific "loading" of the enclosures on each side of the heater in the model and in actuality. Radiant flux density was measured with a special radiometric instrument designed by the Institute of Technical Heat Physics, Academy of Sciences of the Ukrainian SSR [8].

The measurements involved the establishment of an interrelation between the radiant flux and the emf of the thermoelement. To reduce the error of measurement, the housing of the instrument was maintained at a constant temperature by water circulating through the cavity. The electrical signal from the detector was recorded with a KP-59 potentiometer.

The radiation density (W/m^2) was determined from the expression

$$E = K_c e \pm 5\%.$$

The instrument was calibrated after each sufficiently large set of measurements. The radiant component of heater emission was determined by the technique proposed in [9]. For this purpose, a hemisphere with its center at the point of intersection of the diagonals of the heater was divided into a series of spherical bands, each of which was divided into an identical number of equal areas. The radiation density at these areas was measured and then the average radiation density E_b in each band was determined and the radiation intensity obtained by multiplication by the area of the appropriate spherical band. The radiant component of heater emission was obtained by summing over all spherical bands. Measurement of radiation density in each area was made with a locater in the form of an arc made of hollow tubing along which the detector was moved and the relative angular position of detector and heater recorded.

The gas flow rate was measured with a GSB-400 meter. Spectral characteristics were studied with an IKS-11 spectrometer using standard techniques.

Irradiance Fields. The conditions for heat transfer from an IR heater can be considered, under certain assumptions, as a system consisting of a source and sink of electromagnetic energy, and the region of space within the heated volume as an electromagnetic field for which the magnitude of the radiation density is a macrocharacteristic. Without construction of the irradiance field, it is impossible to construct the temperature field, the concept and magnitude of which are fundamental in engineering methods for the design of heating systems. Results of measurements of radiation density for a GIIV-1 IR heater in two mutually perpendicular directions are shown in Fig. 1 for installation heights from 3 to 11 m. The figure makes it clear that the heater produces unequal irradiance fields along the symmetry axes and their intensity depends strongly (nearly proportional to the square of the distance) on the height of heater installation and weakly (±10%) on direction along the symmetry axes.

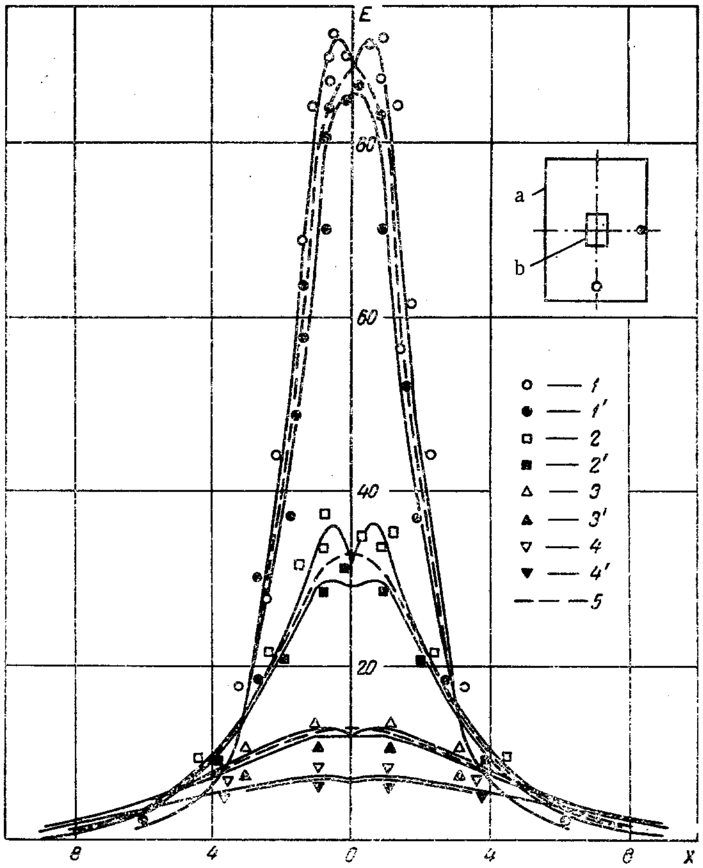

Fig. 1. Irradiance fields (a, scale model) for GIIV-1 (b): 1,1') h = 3 m; 2,2') h = 5 m; 3,3') h = 8 m; 4,4') h = 11 m; 5) from Eq. (1). E, W/m^2; X, m.

TABLE 1. Dependence of E_0 (averaged) on P and of b and c on h

$P \times 10$, Pa	10	12	14	16	18	20
E_0(W/m^2) at $X=0$, $h=1$ m	600	650	750	800	850	900

h, m	3,0	4,0	5,0	6,0	7,0	8,0	9,0	10	11	12
$b \times 10^2$	27,5	15,1	9,2	5,4	3,1	1,9	1,0	0,6	0,55	0,5
$c \times 10^2$	152,3	167,5	182,5	198,0	213,0	228,0	246,0	262,0	275,0	278,0

In the normal direction near the projection of the center of the heater, a reduction in surface radiation density is observed because of the effect of the channels for escape of the gas—air mixture, the temperature of which is 100-150°C below the temperature of the heat-radiating ceramic surface. The density of the radiation field of a GIIV-1 IR heater is well described by the empirical formula

$$E = \frac{E_0}{h^2} \exp[-bx^c], \tag{1}$$

where E is the radiation density at a distance X from the projection of the center of the heater; E_0 is the radiation density at X = 0 and for a height h = 1 m (for nominal gas pressure ahead of the heater, one can tentatively assume E_0 = 820 W/m^2 and use values in Table 1 for other gas pressures); $1/n^2$ is a dimensionless function of heater installation height; b and c are dimensionless coefficients which depend on height of heater installation (Table 1).

Analytic values of E obtained from Eq. (1) are shown by the dashed curve and differ from the experimental values by 5-7%, which can be considered satisfactory, since asymmetry of the field along heater axes was not included in the analytic approach. The optimal region for

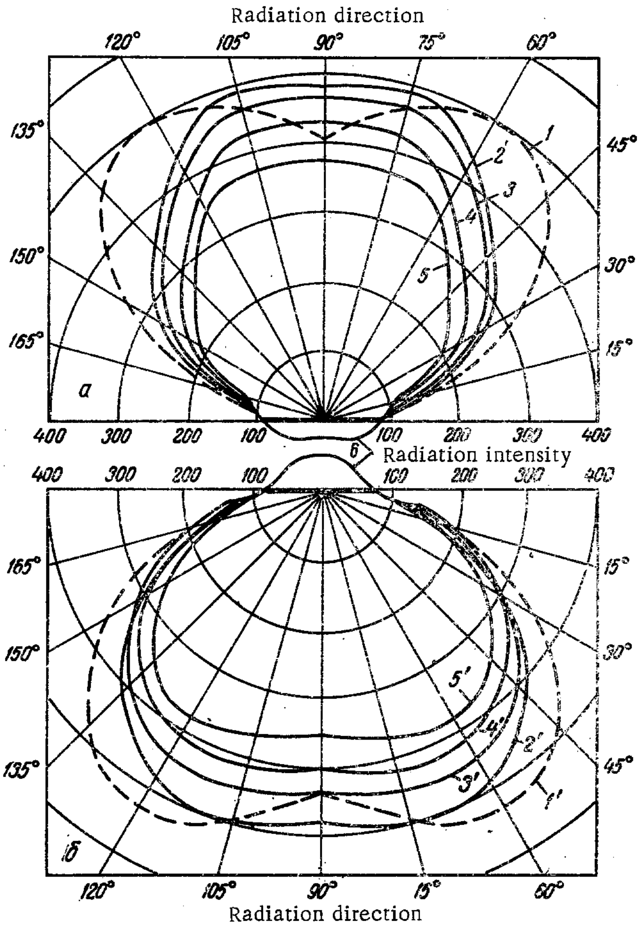

Fig. 2. Radiation intensity curves (W/stere) for heat-radiating surface of GIIV-1 positioned upwards (a) and downwards (b). 1,1') From expression $I_T = (\varepsilon\sigma_0/\pi)(T/100)^4F_e \cos \varphi$[4]; 2,2') I_e = 11.3 and $10.4 \cdot 10^4$; 3,3') I_e = 10.4 and $9.3 \cdot 10^4$; 4,4') I_e = 8.8 and $8.5 \cdot 10^4$; 5,5') I_e = 7.9 and $7.6 \cdot 10^4$; 6) curve for heater housing.

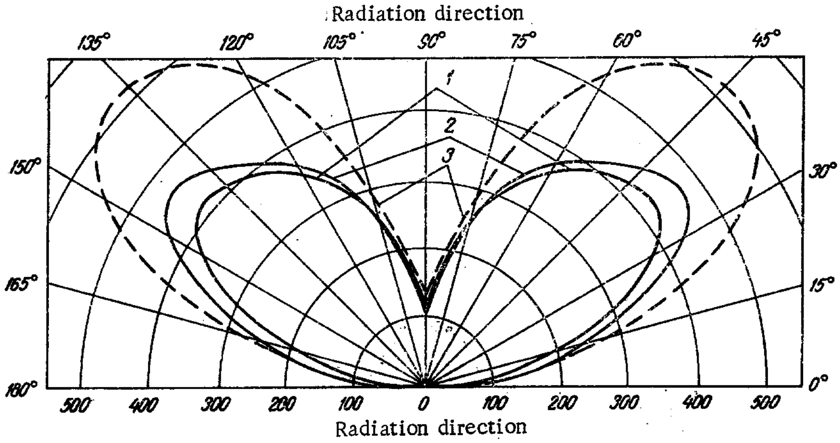

Fig. 3. Curves of radiation power (W) of GIIV-1 for heat-radiating surface upwards (1) and downwards (2) and of an absolutely black body (3).

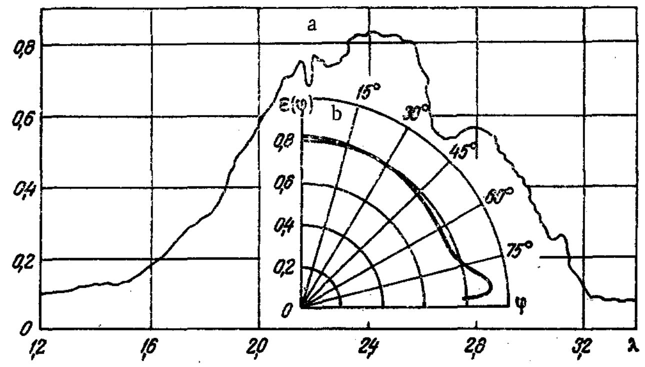

Fig. 4. a) Spectral radiation density (rel. units); b) directional dependence of integral hemispheric emissivity for GIIV-1. λ, μm.

TABLE 2. Average Values of η for GIIV-1

Type of heater installation		η, %	
	ceramic	housing	total
Flame downwards	59	13	72
Flame upwards	51	7	58

the application of Eq. (1) is one in which the temperature of the enclosures is maintained at the level of 285-293°K, their integral emissivity is 0.8-0.9, and the height of heater installation is greater than 3 m.

Radiant Efficiency. Results of measurements of the radiative component of the heat emission from a GIIV-1 are shown in Figs. 2 and 3. Analysis of the data shows that the curve characterizing radiation intensity depends on the position of the instrument in space and on the thermal load, and has a marked directional nature. A comparison between the data obtained and theoretical data [4] indicates that the theoretical data correctly describe the behavior of the radiation intensity curves in the main, but differ considerably from the experimental data with respect to absolute value and angular distribution.

Results obtained for the average values of the radiant efficiency are given in Table 2 for the nominal mode of a GIIV-1. The dependence of η on q_0 was also investigated. The maximum value ($\eta = 85\%$) corresponds to $q_0 = 7 \cdot 10^4$ W/m² and drops with further increase in thermal load, being 40-45% at most when $q_0 = 17 \cdot 10^4$ W/m². Such a situation is explained by the increase in the cooling effect of combustion products, the amount of which rises with increase in the specific heat load.

Emissivity. In the general case, the functional dependence of the emissivity of a gas IR heater will have the following form:

$$\varepsilon = f(T_1, T_2, T_3, T_4, T_5, S_n, d, X_0, X_n), \tag{2}$$

where T_1 is the temperature of the ceramic, T_2 is the temperature of channels of diameter d for passage of the gas—air mixture, T_3 is the temperature of the layer of combustion products beneath the grid, T_4 is the temperature of the grid, T_5 is the temperature of the layer of combustion products above the grid, S_n is a complicated function which takes into account the roughness of ceramic and grid, X_n is a function which takes into account the chemical composition of the radiating components, and X_0 is a quantity which characterizes the effect of environmental factors.

It is obvious that the determination of the expression (2) in explicit form by an analytic method entails insurmountable difficulties.

Experimental data from a study of the angular distribution of the emissivity of heat-radiating surfaces of the GIIV-1 and from a study of spectral radiation density are shown in Fig. 4a,b. The emissivity has the highest value in the angular range 0-30° and tends to zero at angles close to 90°. An increase in emissivity is observed at $\varphi = 75°$ because of the influence of protective screens. At nominal thermal operating modes of the heater, the average values of the emissivity of the heat-radiating surfaces are $\varepsilon' = 0.79$, $\varepsilon_\perp = 0.82$, and the emissivity is markedly dependent on temperature. Thus $\varepsilon' = 0.92$ when $T = 873°K$ and with increase in temperature falls to 0.82 when $T = 1173°K$. The quantity ε_λ is 0.75-0.90 in the range $\lambda = 1.2$-2.2 μm, which corresponds to maximum absorption by the skin of humans.

NOTATION

E, radiation density; K_c, calibration constant; e, electromotive force (emf); Q_r, radiative component of total heat emission; Q_t, total heat emission; $\eta = (Q_r/Q_t)\cdot 100\%$, radiant efficiency; I_φ, radiation intensity in a given direction, W/stere; $I_\perp$, radiation intensity in the normal direction; φ, angle measured from the perpendicular to the heat-emitting surface; h, height of heater installation; σ_0, Stefan–Boltzmann constant; T, temperature; F_e, effective area of heat-emitting surface of heater; q_0, specific heat load; P, gas pressure; ε, emissivity (ε_φ, in a given direction; $\varepsilon_\perp$, in the normal direction; ε_λ, spectral emissivity; ε', integral emissivity); λ, wavelength.

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MEASUREMENT OF THE WAVE PARAMETERS OF LIQUID FILM FLOW BY THE METHOD OF LOCAL ELECTRICAL CONDUCTIVITY

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A method of measuring the wave parameters of a liquid film is described which differs from those known earlier in that it permits the simultaneous determination of the phase velocity, length, and amplitude of the waves and provides a greater volume of information.

Knowledge of the hydrodynamic laws of liquid film flow (thickness of the film and phase velocity, length, and amplitude of the waves) is necessary for the calculation of technological processes in different fields of engineering [1, 2]. A number of methods exist for their measurement [3-7], each of which has its drawbacks, and not one of these methods permits the simultaneous measurement of all the hydrodynamic parameters.

These drawbacks can be avoided with the use of the method of local electrical conductivity, which consists in the direct recording of the instantaneous values of the strength of the current passing through the liquid film between two electrodes located in the immediate

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