RADIATION HEAT TRANSFER IN A SYSTEM OF SEMITRANSPARENT SCREENS BY A LIGHT MODEL

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Principles are proposed for the construction of photoelectric apparatus for light modeling; dependences of the resultant radiation on the geometric and radiation properties of a system of semitransparent screens are obtained experimentally.

Light modeling is an efficient method of investigating radiation heat transfer, determining the opticogeometric characteristics of units and heat-transfer apparatus. The bases, technical and in principle, for light modeling were examined in [1]. However, despite the broad diversity of the constructions of experimental setups and the investigation methods to determine the capacity of beams by semitransparent materials, there are extremely few papers in the literature expanding on the cumulative experience to the present. Only quite brief descriptions of the methods and the appropriate constructions of the installations are presented in a number of papers [2-5].

The principles for constructing and selecting light model elements for radiation heat transfer in a heat exchanger are given a foundation in this paper. Experimental investigations of the attenuation of visible beams passing through a system of semitransparent screens are performed on their basis.

A plate heat-exchanger in whose channels perforated spacers (Fig. 1) were inserted, whose transmission coefficient D, equal to the ratio between the area of the perforations and the area of the continuous unperforated spacer, is variable, was the object of in investigation.

Because of difficulties in the mathematical description of the radiation heat transfer between the structure elements, light modeling was used. The following assumptions are customary here: it is assumed that the luminous surface of the model is similar to the emitting hot wall of the heat-exchanger channel with respect to the intrinsic radiation and the geometric characteristics of the surface itself; the equality of the absorptivity and reflectivity of the heat-exchanger surfaces is conserved for the model and the heat exchanger.

The emitting surface of the heat-exchanger channel was modeled by a luminous surface fabricated from a fluoroplastic plate exposed to a set of low-voltage electric lights (Fig. 2). The plate was covered on the model side by a gray paint so that the optical properties of this coating, the reflectivity and absorptivity in the visible spectrum range, would correspond to the analogous magnitudes of the emitting surface of the heat-exchanger channel wall.

To increase the fraction of light flux used, a reflector whose surface was covered by a material with a high reflection coefficient, anodized aluminum, say, and was well polished was used in the experimental setup. In order to increase the reflectivity of the surface, it was arranged in such a manner relative to the incident radiant flux that acute angles were formed between the incident and reflected beams.

The main requirement on the current sources supplying the electric lamps was stability of their voltage, on which the stability of the luminosity of the emitting surface of the model depends during the tests. The universal supply source UIP-2 was used as such a source.

The perforated spacer surfaces, whose intrinsic emission is quite small compared with the heated wall surfaces of the heat-exchanger channel, were modeled by perforated screens or meshes with appropriate transmission coefficients. The surfaces of the model screens were covered by a paint obtained by mixing different paint concentrations, zinc white with black.

The illumination was measured by using an FÉS-2 photocell in the model under consideration. Satisfaction of the following constraints was here required: 1) to diminish the in-

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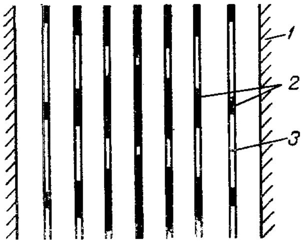

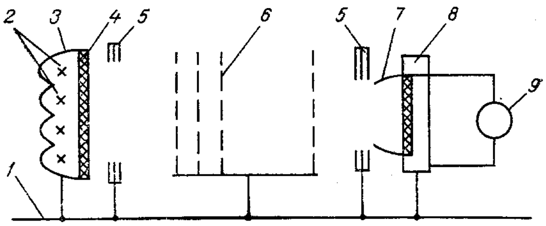

Fig. 1 Fig. 2

Fig. 1. Element of a heat-exchanger channel: 1) radiating channel wall; 2) perforated spacer; 3) perforation in the spacer.

Fig. 2. Diagram of the experimental installation: 1) optical rails; 2) light source; 3) reflector; 4) fluoroplastic plate; 5) iris; 6) packet of semitransparent screens; 7) parabolic mirror packing; 8) photocell; 9) microammeter.

TABLE 1. Geometric Parameters of the Semitransparent Screens

Type of screen	Characteristic dimension, mm	Dimension of a perforation hole element, mm	Transmission factor D
Perforated plate	Thickness	Diameter	
	0,2	3,0	0,251
	0,2	9,9	0,550
	Wire diameter	Side of the square	
Metal mesh	0,25	0,65	0,521
	1,0	3,20	0,582
	0,45	2,0	0,666
	1,0	4,6	0,675
	0,15	0,95	0,716
	0,30	1,62	0,752
	0,30	3,35	0,850
	0,15	2,62	0,90
	0,15	5,55	0,951
	0,15	9,65	0,972
	0,15	14,61	0,980
	0,12	23,7	0,990

fluence of the light-receiving surface of the photocell on the accuracy of the measurement, an iris with a window whose dimensions were smaller than the photocell light-sensitive surface was installed in front of the photocell while a parabolic mirror head was fastened for a uniform light flux distribution over the whole light-sensitive surface of the photocell; 2) the selection of the photocell and the magnitude of the source luminosity were realized in such a manner that the domain of the dependence of the measurable electrical magnitude on the surface illumination was within the limits of the linear section of the photocell characteristic.

If the luminous surface of the model is represented as a set of point sources of luminosity B, then the magnitude of the light flux $d\Phi$ reaching the sensitive surface of the detector dS at a distance r from the luminous surface is expressed as

$$d\Phi = B\,\frac{dS\cos\alpha}{r^2}\,. \tag{1}$$

Taking into account that $dS_n = dS\cos\alpha$ is the projection of the surface receiving radiation on a plane normal to the light flux direction, (1) can be written thus

$$d\Phi = B\,\frac{dS_n}{r^2}\,. \tag{2}$$

Expression (2) permits determination of the geometric parameters: the spacing between the emitter, which is the luminous surface, and the detector, which is the light-sensitive area of the detector depending on the selected luminosity for the emission source.

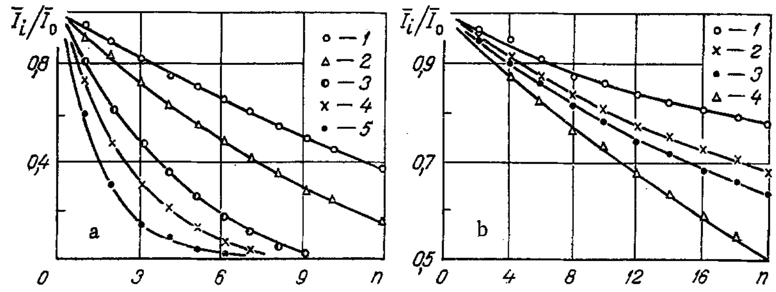

Fig. 3. Dependence of the relative photocurrent $\bar{I}_i/\bar{I}_0$ on the number n of screens per packet for different transmission factors D: a: 1) D = 0.90; 2) 0.85; 3) 0.752; 4) 0.662; 5) 0.521; b: 1) D = 0.99; 2) 0.98; 3) 0.972; 4) 0.951.

To clarify the qualitative influence of the different parameters of the system of semitransparent screens on beam attenuation, an experiment was formulated. The experimental component modeling the perforation of the heat-exchanger spacers was a rod with cuts in which the perforated or mesh screens were installed. The rod was fastened to a support which could be displaced along optical rails.

The magnitude of the photocurrent was determined by an MA-350/5 microammeter with class 0.5 accuracy.

The semitransparent screens of size 60 × 60 mm were fabricated from metal plates or metal grids. The screen transmission factor D varied between 0.251 and 0.99. Presented in Table 1 are the geometric parameters of the semitransparent screens under investigation. The number of screens per packet varied between 1 and 22, depending on the transmission factor, while their number was increased until the photocell reacted to the passing light flux.

The resultant light radiation flux passing through the packet of semitransparent screens was measured in the first series of tests for different values of the transmission factor and the number of screens per packet. The spacing between the detector and the luminous surface and also the screens remained constant here and was, respectively, 280×10^{-3} and 5×10^{-3} m.

The relative error in the measurement results in the experiments (Fig. 3) did not exceed 3%. As is seen from Fig. 3, for a packet of screens with constant absorptivity $A_i = 0.75 =$ const and $D \gg 0.5$, the light flux incident on the photocell receiving surface depends in great measure on the number of screens in the packet and then on the transmission factor. Thus, for four screens whose transmission factor is between 0.52 and 0.72, the dimensionless magnitude of the light flux diminishes more than threefold. The packet of semitransparent screens becomes opaque at D = 0.52 for n = 7 and at D = 0.752 for 10 screens. Analysis of the dependence $\bar{I}_i/\bar{I}_0 = f(n, D)$ shows that for the very same number of screens the nonlinear dependence of the relative magnitude of the photocurrent on the number of screens becomes linear starting with D > 0.85, as D increases (Fig. 3a).

In the second series of tests, the influence of the absorptivity of the semitransparent screen surfaces A_i (i = 1, 2, ..., n) was investigated on the dimensionless magnitude of the light flux. In the different tests the screen surfaces or grid wires were scraped off and then covered with carbon soot, gray paint, zinc white. The values of the integral absorptivity A for the surface coatings of the semitransparent screens were taken from [6] and equalled, respectively, 0.95 for carbon soot, 0.952 for the candle soot, 0.75 for light gray paint, and 0.30 for the zinc white.

As is seen from Fig. 4, for low values of the screen transmission factor $D \ll 0.55$ an increase in the surface absorptivity substantially diminishes the radiation passing through the screen packets (Fig. 4a, curves 2 and 4). When the screen transfer factor increases D > 0.85, the influence of the absorptivity of the surface is negligible, which is explained by the high capacity of the packet of semitransparent screens (Fig. 4b, curves 1, 3 and 5, 6). For a small number of semitransparent screens (n < 3), the influence of A_i (i = 1, 2, ..., n) is also negligible. As the number of screens grows, when multiple reflection starts to be effective in the system, an increase in A_i results in a substantial diminution in $\bar{I}_i/\bar{I}_0$. Thus for n = 6 and D = 0.55 the difference between the quantities $\bar{I}_i/\bar{I}_0$ for semitransparent screen surfaces covered with zinc white and gray paint is ∿63% (Fig. 4a, curves 3 and 5). As the ab-

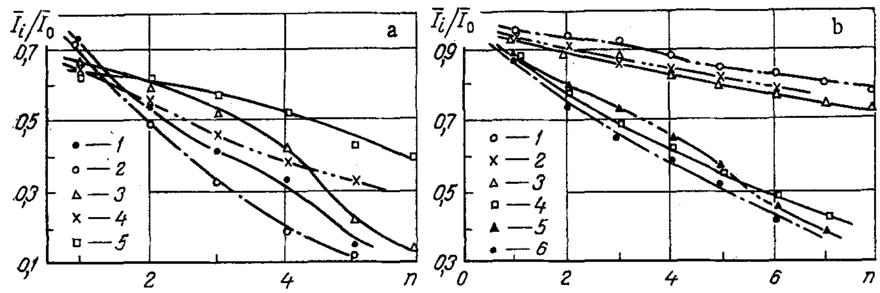

Fig. 4. The dependence of $\bar{I}_i/\bar{I}_0$ on n for different values of the absorptivity of screen coatings: a) D = 0.61 for 1, 2 and 0.55 for 3, 4, 5; 1, 3) light gray paint; 2, 4) candle soot; 5) zinc white; b) D = 0.95 for 1, 2, 3 and 0.85 for 4, 5, 6; 1, 5) electrical insulation varnish; 2, 4) zinc white; 3, 6) candle soot.

sorptivity of the screen surface coatings diminishes, for instance, of the zinc white or colorless varnish, the magnitude of the light flux passing through the packet of screens increases for n = const (Fig. 4b, curves 1 and 5).

NOTATION

α, angle between the direction of light propagation and the normal to the receiving surface; B, luminance; Φ, light flux; S, area of the receiver sensitive surface; r, spacing between the luminous and receiving surfaces; D, transmission factor of a semitransparent screen; n, number of screens per packet; $\bar{I}_i/\bar{I}_0$, dimensionless magnitude of the photocurrent that equals the ratio between the mean values of the photocurrent in the presence of a system of semitransparent screens between the luminous surface and the receiver $\bar{I}_i$ and without it $\bar{I}_0$; and A, absorptivity of the semitransparent screen surface.

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