CONDITIONS FOR THE APPLICATION OF A RADIATION

PARAMETER IN ENGINEERING CALCULATIONS

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The influence of the Boltzmann criterion, the radiation characteristics of the medium and the surfaces, and geometric characteristics of the aggregate on the radiation heat transfer in furnaces are considered.

Criterial dependences are used in studying the operation of thermotechnical aggregates. For high-temperature aggregates in which radiant heat transfer plays a dominant part, the governing criteria are the Boltzmann criterion $Bo = w/l^2\sigma_0 T_t^3$, the Bouger criterion $Bu = \alpha h$, the dimensionless temperature of the beginning of the process $\theta_1 = T_1/T_t$, and the absorptivity of the heating surface a_r.

We performed calculations of the radiation heat transfer in models of several furnace chambers in order to investigate the influence of the mentioned criteria and the geometric configuration of the system on the quantity θ_y (and therefore, on the heat elimination).

An artificial method is used to cut down the number of criteria: the quantity $\varepsilon_v H_r$ is introduced instead of the quantity l^2 in the Boltzmann criterion, where ε_v is the visible emissivity of the chamber taking account of the influence of Bu, a_r, and the geometric configuration of the system [1]. The parameter

$$\pi_p = \frac{\varepsilon_v}{Bo} = \frac{H_r \varepsilon_v \sigma_0 T_t^3}{w}$$

is obtained which, as in [2], we designate as radiative. The influence of θ_1 is taken into account only by a change in the theoretical combustion temperature.

Hence, π_p is used to determine θ_y in boiler furnaces [3]:

$$\theta_y = \frac{(Bo/\varepsilon_v)^{0,6}}{M + (Bo/\varepsilon_v)^{0,6}}, \qquad (1)$$

where M is a constant taking account of the burner arrangement.

In our computations ε_v is found by means of formula 31.XII [1]:

$$\varepsilon_v = \frac{a_f[1-a_f\, \psi - \varphi(1-a_f)]}{a_f + \psi[1-2a_f - \varphi(1-a_f)]};$$

the values of θ_y obtained are represented graphically in the coordinates π_p^{-1}, θ_y.

We consider radiation heat transfer in a gray gas flow moving uniformly in a slot channel of infinite width, bounded by surfaces AB and CD along the flow and by the adiabatic surfaces AC and BD, which are permeable for the gas (Fig. 1), across the flow. Two models were investigated: the first when both surfaces AB and CD are ray-perceptive, and the second when AB is ray-perceptive but CD is an adiabatic wall. A one-dimensional computing scheme is taken; i.e., the gas temperature is considered identical along the channel height. To simplify the computations all the surfaces are taken absolutely black and the heating surface temperature is zero. The gas stream enters the channel at a given temperature T_1. There is no heat liberation in the volume. The computation is performed by a zonal method with the chamber separated into 40 zones along the length for model 1 and into 20 zones for model 2.

An analysis of the results of a computation, contained in Table 1, shows that θ_y is an increasing function of Bo and a decreasing function of Bu and l/h.

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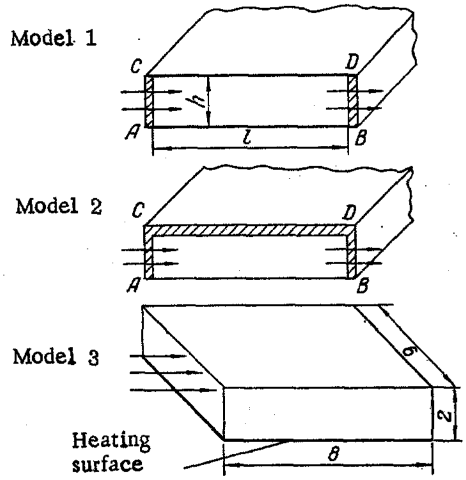

Fig. 1. Chamber models.

TABLE 1. θ_y for Models 1 and 2 (upper row, model 1, lower, 2)*

Bo	l/h=4, Bu 0,2	0,4	1	2	8	l/h=8, Bu 0,2	0,4	1	2	8	l/h=16, Bu 0,2	0,4	1	2	8
2	879	828	768	742	733	879	828	768	742	733	879	828	768	742	733
	828	784	753	744	739	828	781	746	739	738	828	781	745	738	737
1	803	737	668	641	630	803	736	666	638	629	803	736	666	638	628
	738	689	656	647	640	735	681	644	636	634	735	680	641	634	633
0,5	707	636	573	546	532	707	633	568	542	534	707	633	567	542	532
	638	592	559	549	541	632	580	544	537	535	631	574	538	531	531
0,25	606	545	498	473	457	605	540	487	460	447	604	538	482	453	443
	542	500	470	460	449	533	485	451	444	441	528	478	444	438	437
0,167	554	504	446	418	401	551	496	430	404	394	550	492	423	399	391
	488	451	424	413	401	479	356	402	395	392	473	425	394	388	388
0,083	472	416	364	343	327	466	403	349	329	320	462	396	342	323	317
	407	377	353	342	329	396	356	329	322	319	387	346	319	315	314

*Numbers given after the decimal since $\theta_y < 1$.

The quantity

$$\delta = \frac{\theta_y(l/h=4) - \theta_y(l/h=16)}{\theta_y(l/h=16)}\ 100\ \%$$

is represented in Fig. 2a. The influence of l/h on θ_y is insignificant for both models for values of Bo > 0.5.

The dependence (curve 1) of θ_y on π_p for models 1 and 2 is given in Fig. 3a. It is seen from the figure that all the points were on one curve with an insignificant spread, independently of the quantities Bo, Bu, and the geometric relationships in the chamber.

Results of computations of the radiation heat transfer by a zonal method are presented in Table 2 for the section of a holding furnace in the form of a rectangular chamber (model 3 in Fig. 1) 8 m long, 6 m wide, and 2 m high. The wall is adiabatic, $a_w = 0.7$. Fuel combustion is momentary. It is seen from the table that θ_y grows with the increase in reflectivity of the heating surface.

Values of θ_y in the form of a dependence on π_p are represented by points in Fig. 3a. Excluding the point with $a_r = 0.2$ (such absorptivity of the heating surface is not encountered in practice in holding furnaces), we obtain that θ_y can be considered as a single-valued dependence of the radiation parameter.

The heat transfer in the holding furnace model is computed by dividing the working space into a small number, 5, of zones. Hence, for identical π_p its values of θ_y were obtained higher than θ_y for models 1 and 2.

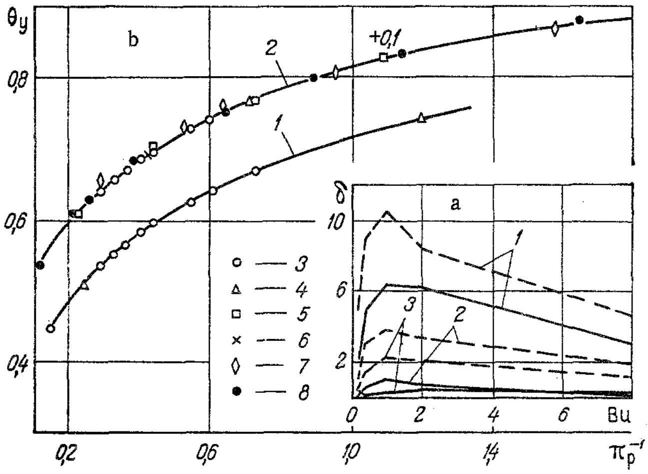

Fig. 2. a) Dependence of the quantity δ, % on the criterion Bu for different values of Bo; solid lines are for model 1, dashes are for model 2 [1) Bo = 0.083; 2) 0.5; 3) 1]. b) Data on the heat transfer in the presence of heat liberation; 1) for a rectangular chamber [a_r = 0.7; 3) α = 0.4 m^{-1}; 4) 0.2]; 2) for a Martens furnace; 5) rectangular chamber [α = 0.4 m^{-1}; 3) a_r = 0.7; 4) 0.2; 6) 0.5], model 3 [α = 0.1 m^{-1}; 7) a_r = 0.2; 8) 0.7].

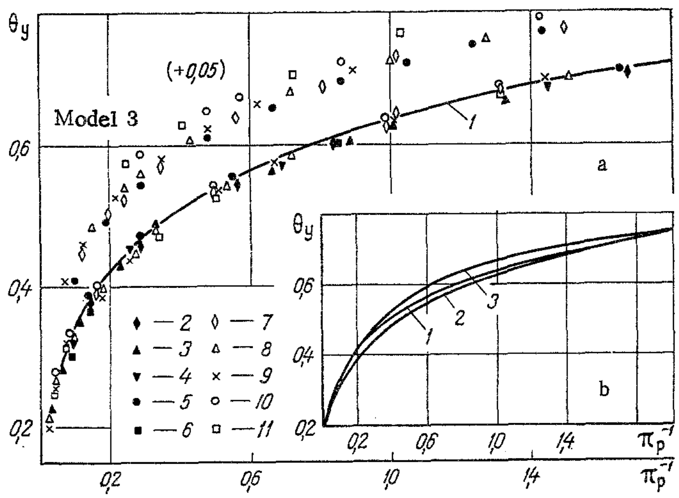

Fig. 3. a) Dependence of θ_y on π_p for models 1 and 2 (curve 1) and model 3: model 1 [for l/h = 8; 2) Bu = 0.2; 3) 1; 4) 8; for Bu = 0.2; 5) l/h = 4; 6) 16]; model 2 for [l/h = 8; 7) Bu = 0.2; 8) 1; 9) 8; for Bu = 0.2; 10) l/h = 4; 11) 16]; model 3 [α = 0.1 m^{-1}; 5) a_r = 1; 7) 0.7; 8) 0.5; 10) 0.2; for α = 1 m^{-1}: 9) a_r = 0.7; 11) 0.2]. b) Dependence of θ_y on π_p [1) for models 1 and 2; 2) from a computation by means of (2), and 3) by means of (1)].

Curve 1 in Fig. 3b corresponds to curve 1 in Fig. 3a. Curve 2 is constructed for values of θ_y computed by a simplified scheme by means of the formula [4]

$$\theta_y = \frac{1}{(1+3\varepsilon_y/\mathrm{Bo})^{1/3}}. \tag{2}$$

Curve 3 corresponds to values of θ_y found by means of (1), where M is taken equal to 0.5.

TABLE 2. θ_y for Sections of a Holding Furnace

Bo	α=0,1				α=1	
	$a_л$					
	0,2	0,5	0,7	1	0,2	0,7
0,048	0,541	0,436	0,401	0,371	0,527	0,364
0,095	0,621	0,512	0,477	0,445	0,603	0,431
0,143	0,668	0,560	0,525	0,494	0,651	0,475
0,333	0,769	0,669	0,636	0,605	0,751	0,576
0,71	0,851	0,768	0,738	0,710	0,820	0,656

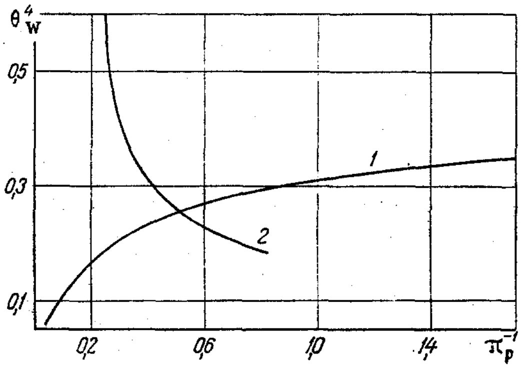

Fig. 4. Dependence of the wall temperature from the side of the gas entry on π_p for model 1: 1) Bu = const = 0.4; 2) Bo = const = 0.25.

It is seen from Fig. 3b that curve 2 differs slightly from curve 1, but curve 3, which is the result of processing test results on radiant heat transfer in the furnaces of boiler aggregates, yields lower values of the heat elimination than curves 1 and 2. The divergence in the values of θ_y belonging to curves 1 and 2 and 1 and 3 does not exceed 0.025 and 0.035, respectively.

Data on the heat transfer in a chamber in the presence of heat liberation with the ratio of the magnitudes of the heat liberation at five equal sections of the chamber of 2:1:1:0:0 are presented in Fig. 2b. The computation for curve 1 was performed by a 10-zone scheme, and for curve 2 by a 5-zone scheme. The former combines the results of computations in a square 1 × 1 m chamber with different α taken from [5].

Curve 2 is the result of computations for a Martens furnace model of 5 × 3 m section, 15 m length, and a section of a holding furnace (model 3). Here values of θ_y for a rectangular chamber, taken from [6], are superposed.

An analysis of this material shows that the nature of the dependence of θ_y on Bo, Bu, a_r does not change with heat liberation within the chamber. If, however, values of θ_y as a function of π_p are considered, then from a comparison between curve 2 (Fig. 2b) and the values of θ_y for the section of the holding furnace (Fig. 3a) it is seen that the presence of heat liberation smooths the spread of the points obtained because of different values of a_r.

Cases of gas motion along a heating surface were considered above. For perpendicular gas motion [7], the general nature of the dependence of θ_y on π_p remains the same. The divergence in the values of θ_y for identical π_p is somewhat higher than in the preceding cases as Bu varies between 0.2 and 1; however, it does not exceed 0.05.

Let us note that no single-valued correspondence exists between π_p and the dimensionless wall temperature θ_w. This is illustrated by Fig. 4, where the dependence of the dimensionless wall temperature from the side of the gas entry on π_p is represented for model 1 for the case when the criterion Bu is constant and the criterion Bo varies (curve 1), and for the case when the criterion Bo is constant while the criterion Bu varies (curve 2).

NOTATION

α, absorption coefficient of the medium, m^{-1}; w, specific heat of the mass flow rate of the gas, W/deg; σ_0, Stefan–Boltzmann constant; T_t, theoretical combustion temperature, °K; T_1, temperature of the beginning of the process, °K; a_r, a_w, a_f, absorptivities of the heating surface, the wall, and the volume of the chamber; H_r, area of the heating surface; l, h, chamber length and height, m; ε_v, visible emissivity; ψ, degree of shielding; φ, angular coefficient between the ray-perceiving surface and itself; θ_y, θ_w, dimensionless temperatures of the waste gases and the wall; Bo, Bu, Boltzmann and Bouger criteria.

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RADIANT HEAT CONDUCTION IN A LAYER WITH A HIGH PARTICLE CONCENTRATION

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The optical thickness of a layer with a high particle concentration is computed by the Monte Carlo method. The radiant component of the heat conduction is found.

The following expression is obtained in [1] for the optical thickness of a medium with a high particle concentration:

$$\tau_0 = \frac{n_0\sigma'}{P'} L. \tag{1}$$

This formula has been obtained in the geometric optics approximation for the case of opaque chaotically arranged particles. To clarify the limits of applicability of (1), a computation has been carried out by the method of statistical tests for the transmissivity of a medium D containing opaque, optically large-scale particles of identical radius. An arrangement of 100 particles of radius 0.075 has been modeled in a volume in the shape of a parallelepiped of dimension 1 × 1 × L. The length dimensionality plays no part in the geometric optics approximation. The coordinates of the particle centers were determined by using a standard program to obtain pseudorandom numbers. The mutual penetration of the particles was excluded. The volume was filled sequentially. The greater the number of particles and the smaller the porosity, the more difficult it is to seek free space for the particles. The porosity was varied between P' = 0.911 and 0.646 by changing the length L of the parallelepiped. A

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