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EXPERIMENTAL INVESTIGATION OF THE TURBULENCE FLOW CHARACTERISTICS BEHIND A SYSTEM OF FLAME STABILIZERS

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Measurements are carried out of the intensity and scale of turbulence in the flow behind a system of flame stabilizers. A comparison is made between the results obtained and the known data for flows behind grills and single stabilizers.

The front assembly of modern straight-through type combustion chambers is a system of flame stabilizers arranged, in practice, in a single plane. The degree of blocking of the flow by the stabilizers may reach 50%. The flow turbulence characteristics behind the front assembly, which mainly determine the fuel combustion intensity and consequently also the length of the combustion chamber, in these conditions should depend in a significant way on the energy of the pulsation motion generated by the flow around the flame stabilizers and by its dissipation mechanism.

Data are available in the literature concerning the turbulence characteristics of the flow behind single stabilizers [1-3] and behind grills of different types [4-7]. There are almost no similar data in the literature for a system of stabilizers. The question concerning what type of flow is closest to the flow behind a system of stabilizers along the fuel combustion zone, to the flow behind a system of single stabilizers or to the flow behind a grill, still remains open.

In this present paper, therefore, measurements have been carried out of the flow turbulence characteristics behind systems of stabilizers, an attempt is made to find a relation between these characteristics and the geometrical dimensions of the system, and also a comparison is carried out between the measured quantities and the similar data for single stabilizers and grills.

The experiments were conducted in models of a combustion chamber of rectangular cross section 170 × 230 mm and 250 × 300 mm, in which two or four plane V-shaped flame stabilizers were installed, with a vertex angle of 45°. The stabilizers were arranged in one plane of

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TABLE 1. Geometrical Dimensions of Stabilizer Systems

Tube dimensions	No. of exptl. points	Δ, mm	H, mm	f, %	No. of stabilizers	ε_0, %
170×230 mm	*1*	17	85	20	2	2,9
	2	27	85	32	2	2,9
	3	34	85	40	2	2,9
	4	17	42,5	40	4	2,9
	5	42,5	85	50	2	2,9
250×300 mm	*6*	40	125	32	2	4,4
	7	40	125	32	2	7,6
	8	40	125	32	2	11,6
175×300 mm [1]	*9*	35	100	60	3	—
175×200 mm [1]	*10*	35	—	—	1	—
		b, mm	M, mm	f, %		
1220×1830 mm [6]	*11*	25,4	203,2	23		
	12	25,4	101,6	44		
	13	76,2	304,8	44		

the chamber cross section uniformly over its height. In order to vary the turbulence intensity of the incident flow on the stabilizers ε_0, quenching grids or turbulence-creating grills were installed in front of them.

The dimensions of the bases of the flame stabilizers Δ, distance between their axes H, degree of blocking of the channel cross section f, and the level of the critical flow turbulence ε_0 are shown in Table 1. The geometrical dimensions of the models used in [1] and the parameters of the grids (size of plates b and distance between their axes M) [6] are also shown.

All the experiments were carried out at a constant air temperature of $T \approx 293°K$ and at atmospheric pressure. The Reynolds number of the flow in the chamber was $Re = 2 \cdot 10^5$; the Reynolds number for the stabilizers was varied from $2 \cdot 10^4$ to $7.5 \cdot 10^4$. The measurements of the turbulence characteristics were carried out by means of a UTA-20 constant resistance thermoanemometer [8]. A platinum wire with a diameter of 10 μm and length 2 mm was used as the sensitive element. The passband of the instrument was 20 kHz. The probe wire was arranged perpendicularly to the flow velocity and parallel to the stabilizer combs.

In order to measure the flow turbulence intensity ε, the signal from the thermoanemometer was fed to a dc and ac voltmeter, from the readings of which were determined the values of u and u'.

For measuring the scale of turbulence L_E, the signal from the thermoanemometer was applied to an M60T amplifier, the frequency range of which was $1-2 \cdot 10^5$ Hz, and then recorded by a TESLA-EMI41 magnetic recorder. The record of the signal was analyzed on a Hewlett-Packard digital equipment, which incorporated a correlator and a spectroplotter. By means of the correlator the autocorrelation function $R(\tau) = \overline{u'(t)u'(t + \tau)}$ was calculated for each analysis. The energy density spectrum of the velocity pulsations u' was determined as the Fourier transform of the autocorrelation function $E(\nu) = 4\int_0^\infty R(\tau)\cos(2\pi\nu\tau)\,d\tau$, which was carried out by the spectroplotter. The magnitude of the scale of turbulence L_E was calculated by the value of E(ν) for $\nu \to 0$: $L_E = \lim_{\nu \to 0} \frac{E(\nu)}{4R(0)}\,u$. It should be noted that when measuring the turbulence scales at close distances from the flame stabilizers, the energy of the harmonic Strouhal motion present in the spectrum was "cut out" by means of narrow-band filters.

Figure 1a shows the change of ε with length, expressed in calibers H, in the plane of symmetry between the flame stabilizers. It can be seen that with increase of x/H the quantity ε starts to increase, reaches a maximum value and then falls. With a constant value of ε_0, the quantity ε is independent of the size of the flame stabilizer bases Δ, and is determined only by the degree of blocking of the flow f. With increase of f, the value of ε increases and the position of the maximum is shifted toward the flame stabilizers.

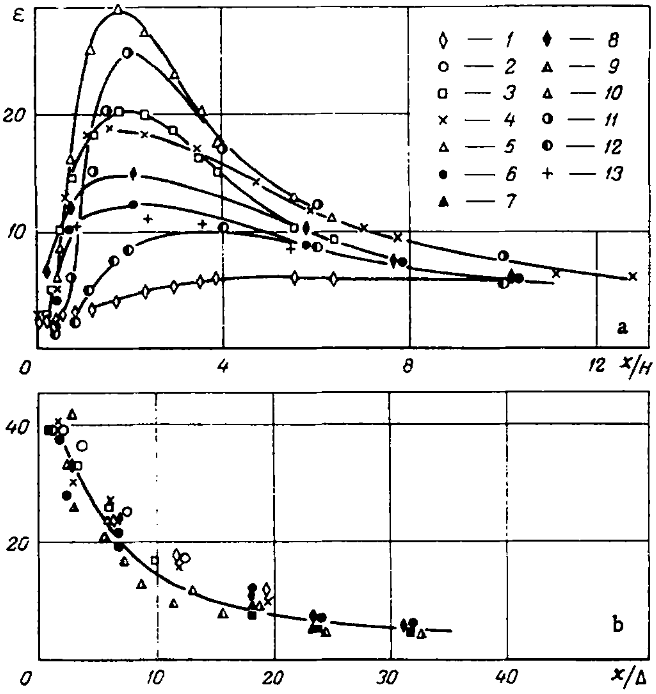

Fig. 1. Change of turbulence intensity (ε, %) along the chamber in the plane of symmetry between flame stabilizers (a) and on the axis of the wake behind the flame stabilizers (b): 13) data of [3]; other symbols as in Table 1.

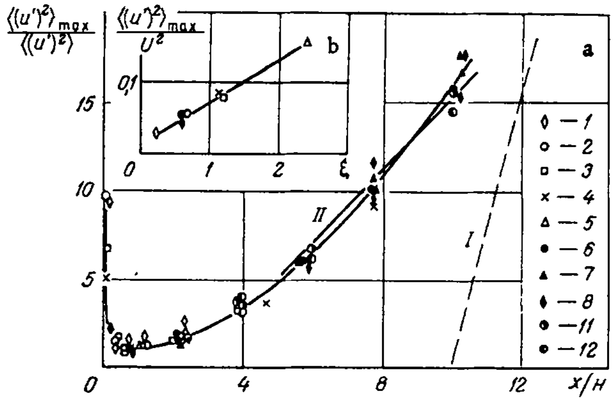

Fig. 2. Variation with chamber length of the quantity $\langle(u')^2\rangle$ max/$\langle(u')^2\rangle$ (a) and dependence of $\langle(u')^2\rangle$ max/U^2 on the drag coefficient of the stabilizer grill (b): I) according to data of [4]; II) data of [5]. Notation same as in Fig. 1.

A change of ε_0 with a constant value of f, in the case when the initial level of turbulence energy does not exceed the energy of the pulsation motion generated by the flame stabilizers, exerts a weak effect on the turbulence intensity of the flow behind the stabilizers. Thus, for Δ = 40 mm, H = 125 mm, and f = 32%, an increase of ε_0 from 4.4 to 11.6% led to a change of the maximum value of ε in the plane of symmetry from 12.5 to 15%. This effect of ε_0 on ε confirms that in the flow behind a system of stabilizers, just as behind grills [7], the energy of the pulsation motion comprises the initial turbulence energy of the flow and the energy generated by the system of stabilizers.

The same figure also shows the processed measurement results of the turbulence intensity ε in the plane of symmetry between flame stabilizers [3] and behind orthogonal grills along the axis of the orifice [6]. All the data coincide satisfactorily with the results of our

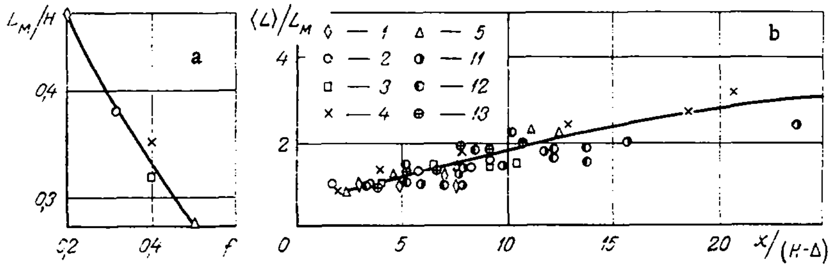

Fig. 3. Dependence of scale of L_M on the geometrical parameters of a system of stabilizers (a) and the change of scale of turbulence along the chamber (b). Notation as in Fig. 1.

measurements, both in the form of the dependence of ε on x/H, as well as in the absolute magnitude of ε. On the axis of the wake behind the flame stabilizer, ε is a maximum in the circulation zone behind the stabilizer and decreases with increase of distance from it. The value of ε at a fixed distance from the stabilizer is determined only by the dimension Δ and is almost independent of ε_0, H, and f (see Fig. 1b). The data given in [1] on the turbulence intensity on the axis of the wake behind a single stabilizer coincides satisfactorily with the values of ε measured on the axis of the wake behind a single stabilizer of the system.

Thus, the magnitude of the turbulence intensity of the flow behind a system of flame stabilizers at small distances from it depends not only on the geometrical characteristics of the system, but also on the choice of the measurement point. On the axis of the wake behind the stabilizers, ε is close to the values obtained on the axis of the wake behind individual stabilizers. In the plane of symmetry between them, ε is close to the values of ε obtained on the axis of the orifice behind the grill. Therefore, when comparing different systems of stabilizers, we will consider the value of the energy of the pulsation motion, averaged over the cross section $\langle (u')^2 \rangle$. The quantity $\langle (u')^2 \rangle$ was found by averaging the field $(u')^2$.

Figure 2a shows the dependence of the ratio of the maximum quantity $\langle (u')^2 \rangle$max for a given system of stabilizers tothe running value on ξ. It follows from the figure that the experimental points obtained for different versions of flame stabilizer systems coincide satisfactorily with one another, forming a unified dependence $\langle (u')^2 \rangle$ max$/\langle (u')^2 \rangle = \varphi(x/H)$. The processed experimental data for the energy damping of the pulsation motion are shown in the same figure for a different type of grill [4-6]. It can be seen that the experimental points of [6] for $x/H > 4$ and the experimental relation established in [5] for $5 \le x/H \le 10$ coincide satisfactorily with the relation $\langle (u')^2 \rangle$ max$/\langle (u')^2 \rangle = \varphi(x/H)$, obtained for the system of stabilizers. The latter, with increase of x/H, approaches the limiting law of turbulence degeneration, established for large distances from the grill [4].

Thus, the mechanism of turbulence energy degeneration behind a system of stabilizers is similar to the mechanism established for the grill.

The relative magnitude of the maximum flow turbulence energy $\langle (u')^2 \rangle$ max$/U^2$ depends only on the drag coefficient of the flame stabilizer system ξ. The form of this dependence is shown in Fig. 2b. The quantity ξ was calculated by the formula [3]

$$\xi = (\sqrt{\eta} + \sqrt{f} - f)^2/(1 - f)^2,$$

where η is the damping coefficient of the inlet, equal in our case to 0.15.

A measurement of the Euler scale of turbulence in the flow behind the system of flame stabilizers showed that on the initial section of the flow, the extent of which amounts to $\approx 2-2.5\ (H - \Delta)$, the quantity L_E in the plane of symmetry between the stabilizers is determined mainly by the scale of turbulence L_{E0}, incident on the stabilizers. On the axis of the wake behind the flame stabilizer, the value of L_E on this part depends mainly on the dimension Δ. At the end of the initial section, a scale of turbulence L_M is developed in the flow, which is almost constant for the whole cross section, and is characteristic for a given system of stabilizers. Then L_E increases in proportion with distance from them.

The quantity L_M, for constant values of ε_0 and L_{E0}, depends on the distance between the axis of the stabilizers H and the degree of blocking of the flow f. The form of this curve is shown in Fig. 3a.

Figure 3b shows the change of the relative scale of turbulence $\langle L_E \rangle / L_M$ with length, expressed in calibers of the distance between the stabilizer combs $(H - \Delta)$. As the value of L_E in the chamber cross section remains almost constant when $x/(H - \Delta) > 2$, the quantity $\langle L_E \rangle$ was assumed to be equal to one-half of the sum of the values of the turbulence scale on the axis of the wake and in the plane of symmetry between the stabilizers. The processed experimental data for the scale of turbulence behind orthogonal grids [6] are plotted in the same figure. The satisfactory agreement of the grill data with the data obtained for a system of flame stabilizers confirms that the mechanism of change of the Euler scale of turbulence at small distances from the system of stabilizers is similar to that established for grills of a different type.

NOTATION

u, the local average flow velocity; u', the mean-square value of the longitudinal component of the pulsation velocity; $\varepsilon = u'/u$, turbulence intensity, defined by the longitudinal component of the pulsation velocity; ε_0, turbulence intensity of the incident flow; ν, frequency of the velocity pulsations; t and τ, times; L_E, Euler longitudinal integral scale of turbulence; x, distance from the scarf of the flame stabilizers; U, discharge flow velocity; and ξ, coefficient of resistance of the flame stabilizer system.

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