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INFLUENCE OF THE GEOMETRICAL AND GASDYNAMIC PARAMETERS OF A MIXER ON THE MIXING OF RADIAL JETS COLLIDING WITH A CROSSFLOW

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Results of investigation of the mixing of a system of axisymmetrical jets with a subsonic carrying flow in a cylindrical channel are presented. The main characteristics of the mixer were varied in wide ranges in the process of experiments. The regime of colliding jets was realized in the majority of experiments. The influence of individual factors on the quality of the mixing was considered. A combination of the mixer parameters within the ranges investigated, optimum for a high-quality mixing, has been determined. The experimental results obtained were compared with the corresponding data of other authors.

Keywords: *mixer, jets in a carrying flow, long-range interaction of jets, quality of mixing.*

Introduction. Mixers with a transverse introduction of jets into the carrying flow are used in different technological facilities, such as the gas burners of boiler plants [1], chemical oxygen-iodine lasers [2], the combustion chambers of gas-turbine plants [3–5], and chemical reactors [6–8]. The design of a mixing apparatus should provide an effective mixing of flows different in the temperature and (or) composition. Moreover, in many cases, additional requirements are imposed upon the mixers, namely, the mixing process should proceed very rapidly. This demand is made, in particular, on the mixers of oxygen-iodine lasers, the combustion chambers of gas-turbine power plants, and different chemical technological apparatus. In [3–5], results of a large number of model experiments, in which the geometry of the mixer of the combustion chamber of a gas-turbine plant working in the rich burning–rapid mixing–lean burning regime was optimized, are presented. In review [8], different chemical processes, for realization of which a very rapid mixing of the components of a working mixture is required because the residence time of a reacting mixture in a reactor comprises several units or tens of a millisecond, were considered. In the schemes of technological processes proposed by the authors of this work, the mixing of the starting-material flow with the heat-transfer gas is performed in a mixer with a transverse introduction of jets into the reactor.

The aerodynamics of a jet in an unbounded carrying flow has long been investigated. A voluminous bibliography of works on this subject and concrete results of investigation are presented in [9–11]. The majority of these works were devoted to investigating an axisymmetric jet. In some works, the characteristics of rectangular and fan (radial-slot) jets in a carrying flow were considered (see, e.g., [3–5, 12]). Data obtained for an isolated jet in an unbounded flow can be used for calculating mixers (a system of jets in a channel) in the case where the depth of penetration of jets into the main flow and the ratio between the rates of the jets and the main flow are small. However, these conditions are not fulfilled in many technological applications where the structure of the flow in the channel of a mixer is determined by the interaction of the jets with each other and with the main flow.

The results of the earlier experimental investigations have shown that the quality of mixing of the jets with the main flow in a mixer, i.e., the homogeneity of the parameters of the flow at its output, depends on the ratio between the momenta of the jets and the main flow as well as on the geometrical characteristics of the mixer, such as the relative length of the channel, the ratio between the diameters of the jets and the channel, and the relative spacing between the holes (or their number). In the case of rectangular holes, in addition to these parameters, the ratio between the sides of the holes and the angle between their axes and the axis of the channel are considered. Since this problem

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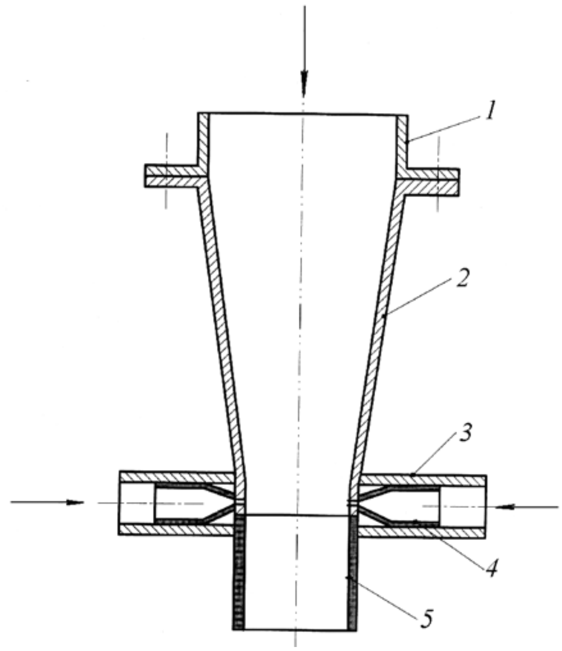

Fig. 1. Diagram of the experimental setup: 1) tube; 2) by-pass channel; 3) pipe connection; 4) nozzle; 5) mixing chamber.

is multiparametric, in each above-indicated experimental work, the influence of only a definite combination of the parameters of a mixer, varying within the range corresponding to concrete technological conditions, on the quality of mixing of the jets with the main flow was simulated.

It may be concluded that the data presented in the literature are insufficient to work out reliable recommendations for determining an optimum geometry of a mixer independently of the combination of its main parameters. Each new investigation in this direction served to widen the database necessary for development of methods for calculating mixers. It is precisely this object that is pursued in the present work, in which the determining parameters of the mixing of jets with a crossflow were varied within wide ranges.

In the present investigation, prominence was given to the work of a mixer in the regime of colliding jets whose paths intersect in the near-axis region of the channel. Such conditions were realized for the first time in the experiments carried out in [7, 13].

Experimental Setup and Measurement Procedure. In our experiments, the main flow was heated and the blown-in gas was cold. The degree of mixing of the jets with the main flow in a mixer was judged from the temperature fields at the exit section of the mixer.

The experiments were carried out on a laboratory stand with an electric-arc heater. The main flow was formed by mixing of the air heated in a plasma generator with a cold air. A room-temperature air was fed to the mixer. The diagram of the experimental setup is presented in Fig. 1 (the plasma generator is not shown in the figure). The profiles of the gasdynamic parameters in the mixer level off in the cylindrical channel and in the narrowing conical insert attached to the mixer. The air supplied for the mixing was taken from a collector; it passed through the hose pipes and was fed to the mixer channel through the changeable nozzles installed in the nozzle unit. The inner contour of a nozzle consisted of two parts: one of them narrowed at an angle of 60^{o} and the other represented a short rectilinear section. The experiments were performed with eight and four jets. In the latter case, the nonworking nozzles were dampened. A mixing chamber was installed in the mixer unit. The inner diameters of the nozzle unit and the mixing chamber were equal to 35 mm. The outer surfaces of the mixing chamber and the conical insert were heat-insulating.

In the process of experiments, the flow rates of the main air and the blown-in air were measured by the method of critical washers, and the pressure in the collector was controlled and corresponded to the pressure at the input of the injection nozzle. The parameters of the flow at the nozzle exit section were calculated by the one-dimensional gas-dynamics equations. In individual experiments, where the flow rate of the blown-in air was large, the pres-

TABLE 1. Geometrical Characteristics of Mixers and Ratios between the Rates of the Jets and the Main Flow in Experiments

L/D	n	S/d	d/D	G_j/G_m
0.5	8	7.2	0.054	0.18, 0.27, 0.54, 1.46
0.5	4	3.6	0.217	0.40, 0.61, 0.90, 2.35
0.5	8	1.8	0.217	1.17, 1.62, 2.3
1	8	7.2	0.054	0.25, 0.53, 1.07, 1.69
1	4	3.6	0.217	0.61, 1.35, 2.31
1	8	1.8	0.217	1.17, 1.62, 2.31
1	8	3.6	0.109	0.70, 1.01, 1.15, 1.49, 2.15, 2.82
1	4	7.2	0.109	0.27, 0.35, 0.51, 0.76, 1.07, 1.41
2	8	7.2	0.054	0.18, 0.25, 0.54, 1.07
2	8	3.6	0.109	0.52, 0.70, 0.99, 1.01, 1.51, 2.11
2	8	1.8	0.217	1.17, 1.62, 2.3

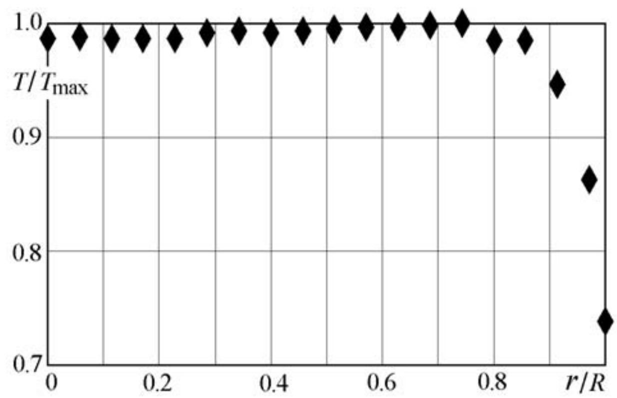

Fig. 2. Temperature profile in the absence of jet blow.

sure drop at the nozzles was supercritical. The temperature profile at the exit section of the mixing chamber was measured by a chromel-alumel thermocouple with a junction of diameter 0.5 mm. The coordinate of the junction was determined by a micrometer. The temperatures of the flow in the planes of the holes were measured along the two mutually perpendicular diameters of the holes in their planes and along the two mutually perpendicular diameters shifted by half the angle between the neighboring holes. In the majority of experiments, the temperature of the flow was measured at 140 points of the exit section of the mixer.

The pressure of the main air was close to the atmospheric pressure. The temperature of this air was 1100–1120 K, and it was maintained in the process of all the experiments. The rate of the main flow in each experiment was equal to G = 13 g/sec. The velocity of the air flow at the input of the mixer was 47 m/sec.

In Table 1, data on the geometry of the mixers used in the experiments and the ratio between the rates of the jets and the main flow G_j/G_m in them are presented. All told, 12 mixers were investigated: three variants of mixing chambers in which the distance between the axes of the holes and the exit section L = 17.5, 35, and 70 mm (the corresponding mixers had a relative length L/D = 0.5, 1, and 2, and the distance L was measured from the axes of the holes) and three variants of nozzles with exit sections of diameter d = 1.9, 3.8, and 7.6 mm (the corresponding mixers had holes of relative diameter d/D = 0.054, 0.109, and 0.217); the number of nozzles n = 4 and 8. The experiments with all the mixers being investigated were performed for several ratios between the rates of the jets and the main flow; in this case, the value of G_j/G_m changed within the wide range — from 0.18 to 2.3 (Table 1).

Results of Experiments and Their Analysis. In order that the measurement results could be interpreted correctly, the profile of the temperature of the flow upstream of the mixer should be uniform. This condition was provided in our experiments. Figure 2 shows the temperature distribution of the main flow along the radius of the channel at a distance of 17.5 mm from the injection section, obtained by averaging of the results obtained over four radii. It is seen that, excepting the region of the thin boundary layer, the initial temperature profile is practically uniform.

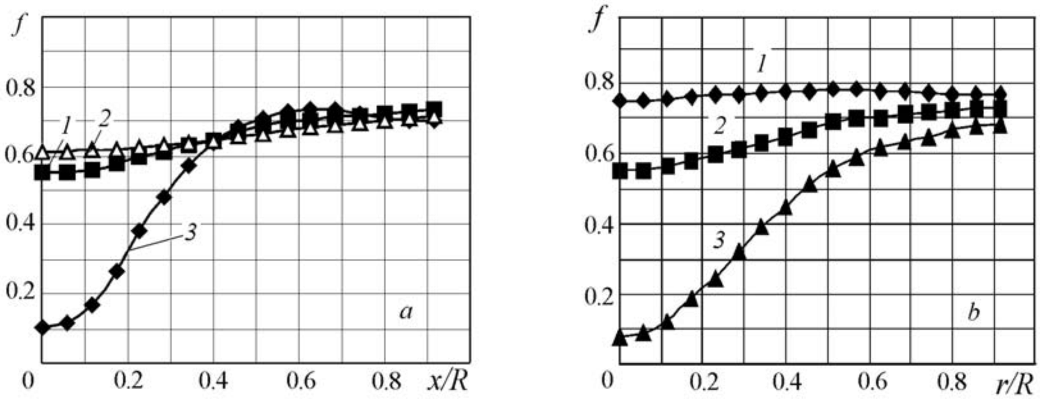

Fig. 3. Dependence $f(r/R)$ for the mixer 8/1.8/0.217 at variable values of the parameters L/D and G_j/G_m: a) L/D = 2 (1), 1.0 (2), and 0.5 (3); b) G_j/G_m = 2.3 (1), 1.6 (2), and 1.2 (3).

Before proceeding to the consideration and analysis of the results obtained, we describe the method used for processing of experimental data in the present work. Traditionally, (see, e.g., [5]) the following parameter is determined by the indications of thermocouples:

$$f = \frac{T_m - T}{T_m - T_j}. \tag{1}$$

For nonreacting flows, the value of f is determined by the concentration of the blown-in substance (see, e.g., [9], p. 610). Expression (1) is true at small differences between T_m and T_j. Since the heat capacity of a substance depends on its temperature, in a more general case (especially at $T_m >> T_j$) it is necessary to use the relation

$$f = \frac{i_m - i}{i_m - i_m}, \tag{2}$$

which rearranges to (1) at $T_m = T_j$. In the case of complete mixing of jets, the value of f is determined by the ratio between the rates of the jets and the main flow

$$f_{eq} = \frac{G_j/G_m}{1 + G_j/G_m}. \tag{3}$$

As an example, in Fig. 3, the distributions of the parameter f over the cross section of the mixing chamber, obtained in several experiments and averaged over the eight radii, are shown. By the dependence $f(r/R)$ we determined the degree of homogeneity of the flow at the exit section of the mixing chamber f'/f_{eq}, where

$$f' = \sqrt{\frac{\int_0^{R_1} (f - f_{eq})^2 \, 2r dr}{R_1^2}}. \tag{4}$$

To avoid the influence of the boundary layer on the calculation results, we considered only the measurement data obtained for the undisturbed core of the flow ($R_1 = 0.9R$).

Figure 3b gives a qualitative estimate of the mixing process with an increasing rate of jets. When the parameter G_j/G_m increases, the profile $f(r/R)$ levels off and becomes practically uniform at G_j/G_m = 2.3. The influence of the length of a mixer on the quality of the mixing is analogous to the influence of the ratio between the rates of the jets and the main flow (see Fig. 3).

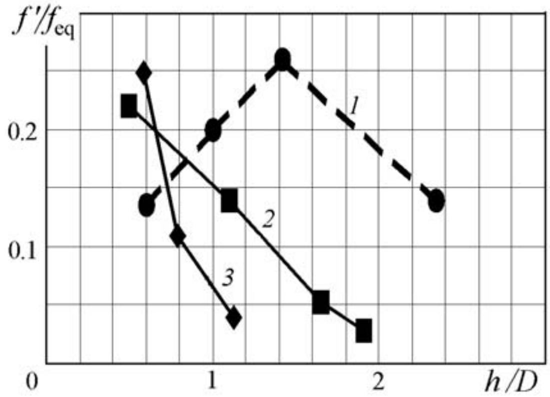

Fig. 4. Inhomogeneity of the flow at the output of the mixing chamber of length L/D = 0.5: 1) 4/3.6/0.217; 2) 8/7.2/0.054; 3) 8/1.8/0.217.

The quality of the flow obtained as a result of the mixing of jets with a crossflow is characterized by the parameter f'/f_{eq} and is determined, in the general case, by the relative sizes of the mixer d/D, S/d, and L/D and the ratio between the momenta of the jets and the main flow $J = \rho_j w_j^2/\rho_m w_m^2$. In the majority of the previous investigations the analysis of experimental data was reduced to the construction of the dependences $f'/f_{eq}(J)$ for a mixer of definite geometry or the dependences f'/f_{eq} at J = const and at an invariable geometry of the holes (see, e.g., [3–5]). In the present work, the results of experiments are presented in the form of the dependences of the value of f'/f_{eq} on the long-range interaction (LRI) parameter h/D. Since the main objective of the present work is to investigate the quality of the mixing of colliding radial jets with the main flow, we should know the conditions under which this regime is realized. To put it differently, the value of h/D should be controlled. Giving preference to the study of the regime of colliding jets, we recognized that, in this case, the collision of the jets increases the turbulence of the flow in the near-axis region of the channel, which enhances the mixing process.

The depth of penetration of a jet into an unbounded crossflow was determined in many works (see, e.g., [9]). In the present work, we used expression, presented in [1], for a system of jets in a carrying flow:

$$\frac{h}{d} = K\sqrt{J}\,, \tag{5}$$

where the coefficient K is determined by the spacing between the holes S/d. Expression (5) can be written in the form

$$\frac{h}{D} = K\frac{d}{D}\sqrt{J} \tag{6}$$

or (with account for the flow coefficient of the nozzle μ) as

$$\frac{h}{D} = K\frac{D}{dn\mu}\frac{G_j}{G_m}\sqrt{\frac{\rho_m}{\rho_j}}\;. \tag{7}$$

In the present work, it is assumed that K = 1.7 [1] and μ = 0.89.

The value of h/D determined by relations (5)–(7) does not correspond to the real depth of penetration of a system of jets into the flow bounded by the walls of the channel even at $h/D < 0.5$ and generally loses physical meaning at $h/D > 0.5$. However, it may be suggested that, at large values of the LRI parameter ($h/D >> 0.5$), at which the regime of colliding jets is deliberately realized, the value of h/D determined by the geometrical characteristics of the mixer and the ratio between the rates of the jets and the main flow will characterize this process to a certain measure.

Below are presented experimental results presented in the coordinates f'/f_{eq}, obtained for three diffent lengths of the mixing chamber: L/D = 0.5, 1.0, and 2.0. In each group of experiments, the variants of mixers differing by the number and diameter of the holes were compared. In the graphs, the geometrical characteristics of the mixers are presented in the following order: $n - S/d - d/D$, and between them there is an evident relation: $\frac{S}{d} = \frac{\pi}{nd/D}$.

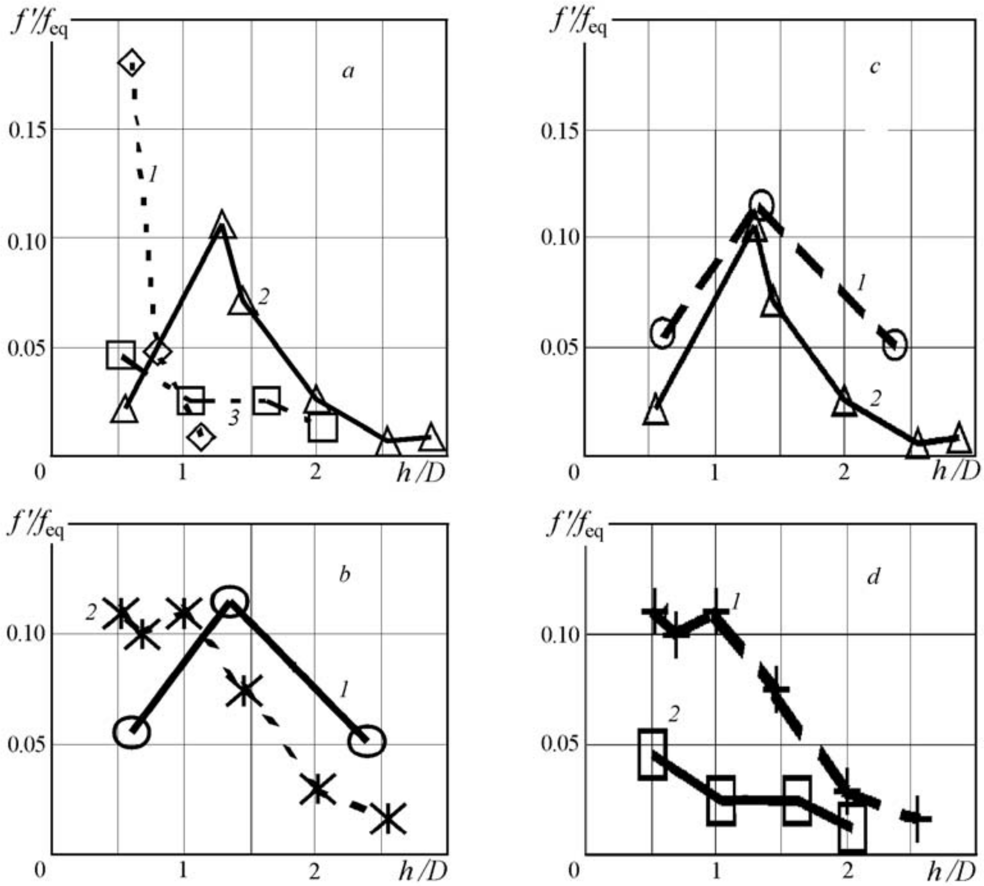

Fig. 5. Inhomogeneity of the flow at the output of the mixing chamber of length L/D = 1: a) 1 — 8/1.8/0.217; 2 — 8/3.6/0.109; 3 — 8/7.2/0.054; b) 1 — 4/3.6/0.217; 2 — 4/7.2/0.109; c) 1 — 4/3.6/0.217; 2 — 8/3.6/0.109; d) 1 — 4/7.2/0.109; 2 — 8/7.2/0.054.

Figure 4 presents results of experiments with the shortest mixing chamber. All told, we investigated three variants of mixers: two mixers with eight holes and one mixer with four holes. In the first two cases, the ratio d/D was changed by a factor of 4. For mixers with n = 8, the dependences $f'/f_{eq}(J)$ were qualitatively identical; however, for the mixer 8/1.8/0.217 a highly uniform flow was obtained at smaller values of the LRI parameter. The dependence $f'/f_{eq}(J)$ obtained for the mixer with four holes was nonmonotonic and, in the range of h/D being investigated, was positioned, as a rule, higher than that of the mixer with n = 8. The nonmonotonic dependence $f'/f_{eq}(J)$ corresponding, in this case, to the dependence $f'/f_{eq}(h/D)$ (see formula (6)) was obtained in other investigations too, e.g., in [4]. In this mixer, small inhomogeneities arise in the flow at larger values of h/D than in the mixers with eight holes. The experimental results presented in Fig. 4 point to the fact that very short mixers can provide efficient mixing of substances.

In our experiments, mixers with a relative length L/D = 1.0 have been studied most thoroughly. The influence of the parameter S/d on the quality of the mixing is illustrated in Fig. 5a. For the mixer with a relative spacing between the holes S/d = 3.6, the dependence $f'/f_{eq}(h/D)$ is nonmonotonic. However, in this case too, at $h/D \geq 2$, the flow at the exit section of the mixing chamber has a very high quality: f'/f_{eq} = 0.02. For the mixers 8/1.8/0.217 and 8/7.2/0.054 the same homogeneity of the flow is attained at much smaller values of $h/D \approx 1.2$. In the experiments with mixers having four holes, a high-quality flow was obtained only at $h/D \approx 2.5$ (Fig. 5b). In Fig. 5c, the results of experiments with mixers differing by the number of holes are compared. It is seen that, as in the case illustrated by Fig. 4 where L/D = 0.5, a less inhomogeneous flow arises in a mixer with a larger number of holes. An analogous comparison, showing the influence of the number of holes on the quality of the mixing, was performed for mixers with different values of S/d, namely, for S/d = 5.2 (Fig. 5d).

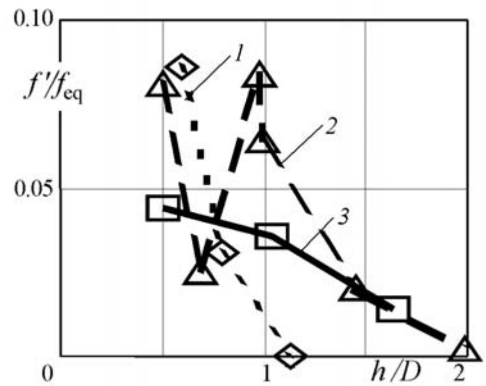

Fig. 6. Inhomogeneity of the flow at the output of the mixing chamber of length L/D = 2: 1 — 8/1.8/0.217; 2 — 8/3.6/0.109; 3 — 8/1.8/0.217.

The dependences in Fig. 5d and c are qualitatively similar; however, when the parameter S/D increases from 3.6 to 7.2, the inhomogeneity of the flow decreases at a constant value of h/D.

For all the mixers presented in Fig. 6, in the mixing chamber of length L/D = 2.0, a high-quality mixing is realized at $h/D > 1.2$, and, for the variant 8/1.8/0.217 the distribution of the concentration of the blown-in substance over the section is close to the ideal one.

The influence of the length of the mixing region on the quality of the flow is illustrated in Fig. 7 where the results of experiments with the mixing chambers of length L/D = 0.5, 1.0, and 2.0 are presented. The change in the parameter f'/f_{eq} with increase in the length of the mixing chamber is one and the same in character for mixers having different values of d/D. This follows from Fig. 7a and b. The inhomogeneity of the flow sharply decreases when L/D increases from 0.5 to 1.0, and a further increase in the length of the mixing chamber influences insignificantly the quality of the flow. In both cases, at $h/D \geq 1$ and L/D = 1.0, a highly homogeneous flow was detected, and it was characterized by the parameter $f'/f_{eq} \approx 0.02$–0.03.

The experimental results presented in Figs. 4–7 point to the fact that the interaction of colliding jets with a carrying flow is complex in character. The processing of data with the use of the LRI parameter h/D allows one to obtain more close dependences $f'/f_{eq}(h/D)$ for mixers having different geometries, as compared to the method of analysis of the dependences $f'/f_{eq}(J)$ that is used sometimes in practice. It is apparent that the role of different factors influencing the quality of the mixing cannot be determined with the use of one parameter. However, the range of values of h/D, where the geometrical characteristics of a mixer insignificantly influence the values of f'/f_{eq}, i.e., where the quality of the mixing is determined mainly by the parameter h/D, can be found. For example, in the case where the length of the mixing chamber L/D = 1.0, a mixer with eight holes provides, at $h/D \geq 1.5$, the formation of a flow with f'/f_{eq} = 0.05–0.02, and in a mixing chamber of length L/D = 2.0 the value f'/f_{eq} = 0.02 is realized at h/D = 1.5. It should also be noted that the efficiency of the mixing in mixers with eight holes is higher (all things being equal) than that in mixers with four holes.

The results of experiments with mixers of different geometry should be compared with account for the following important circumstance. The determination of the parameter h/D for processing of experimental results is based on the assumption that the mixing process is intensified after the collision of the jets. Consequently, in this case, the characteristic size should be the distance from the point of intersection of the axes of the jets to the exit section of the mixer, i.e., the length of the region of intersaction of the jets with each other and the main flow. However, according to the available literature data, it is impossible to determine this distance. For these conditions, we calculated the distance at which the axes of the blown-up jets reach the axis of the channel with the use of the known equation for the path of a jet in an unbounded carrying flow (see, e.g., [1, 11]). In this case, rough results are obtained; however, they allow one to qualitatively estimate the role of the indicated factor with the use of measurement results. It has been established that, in a number of cases, the axis of a jet intersects the axis of the channel at a large distance from the injection site and, sometimes, beyond the mixing chamber. It follows herefrom that the parameter h/D is inadequate to generalize experimental data obtained for mixers having different geometries. The influence of this factor is strongest in short mixers. The data presented in Fig. 3a qualitatively support the conclusion made. It is seen that, in the cen-

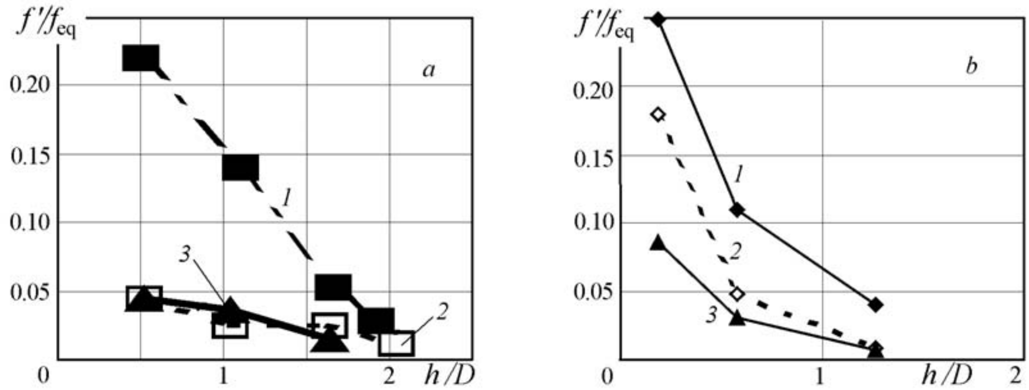

Fig. 7. Influence of the length of the mixing chamber on the quality of the flow for the mixers with holes of different geometry: a) mixer 8/7.2/0.054, L/D = 0.5 (1), 1.0 (2), 2.0 (3); b) mixer 8/1.8/0.217, L/D = 0.5 (1), 1.0 (2), 2.0 (3).

tral part of the exit section of the mixing chamber of length $L/D = 0.5$ the blown-in gas is practically absent, i.e., the region of interaction of jets is shifted to a large distance downstream of the injection site.

To determine the influence of the length of a mixer and the geometry of its holes on the quality of mixing in larger ranges of change in these parameters, it is necessary to compare the results of the present work with the corresponding experimental results of other works [3, 5]. Prior to this comparison we note that in the literature there are numerous data on the characteristics of mixers; however, they have different geometrical and gasdynamic parameters, and, therefore, provide different investigations conditions. Consequently, the experimental results obtained with these mixers are true only for the conditions under which the experiments were carried out. Note that conditions close to the conditions of the present work (but not identical to them) were realized in [3, 5]. The common factor for these works was the regime of work of a mixer — in all the cases, the process of interaction of colliding jets with a crossflow was investigated. Moreover, the values of some geometrical parameters were equal or close. Taken together, these circumstances make the comparison of experimental data more valid.

In the experiments of [3], the dynamics of change in the inhomogeneity of the flow in a mixer in the region where $L/D \leq 0.5$ at J = 25, 50 and 80, $G_j/G_m = 2.2$, and $n = 8$ has been investigated in detail. The diameter of the holes was somewhat changed in accordance with the change in the ratio between the momenta. The aim of work [5] was to determine the optimum geometry of the holes for a mixing chamber of length $L/D \leq 0.5$ at $J = 40$ and $G_j/G_m = 2.5$. In this case, the number of holes in the mixer was changed from 6 to 16. Thus, in [3, 5], the initial data necessary for determining the LRI parameter and, consequently, for processing of measurement results by the method used in the present work are given. According to our calculations, the conditions of experiments carried out in [5] correspond to the values of the LRI parameter h/D = 2.2–3.1 and h/D = 2.2–2.9 respectively.

A comparison of the results of processing of experimental data is presented in Fig. 8. For correctness purposes, the data of [3, 5] were compared with the results obtained in the present work at $h/D \geq 2$, excepting the variant 8/1.80/0.217. A mixer with this geometry was not used in the experiments conducted at large values of h/D, and the point in Fig. 8 corresponds to h/D = 1.15.

The points are denoted by identical symbols; however, their correspondence to a definite geometry of the holes can be determined by Figs. 4–7. The results of experiments with a mixer having four holes, which are not indicated in the graph, drop out of the general dependence. The logarithmic curve in the graph approximates all the experimental data in the range of L/D = 0.01–2.

It should be noted that our data as a whole correlate satisfactorily with the experimental data of [3, 5] for different-geometry mixers working in the regime of colliding jets at $h/D \geq 2$. The weak influence of the geometry of the holes on the quality of the mixing at large values of h/D, detected in our experiments (see Fig. 7), is also characteristic of the conditions realized in [5]. As follows from Fig. 8, the points from this work, corresponding to different values of n and h/D (denoted by one and the same symbols), are positioned fairly close to each other in the graph.

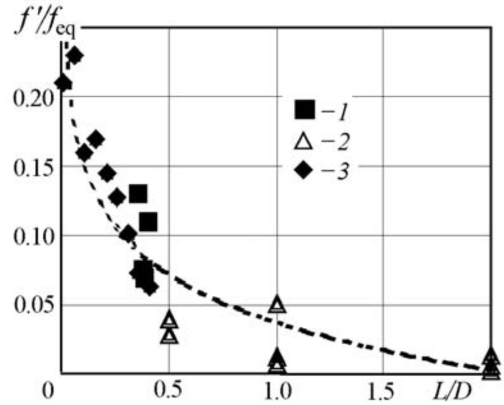

Fig. 8. Comparison of the experimental results of the present work with data of other authors: 1) [5]; 2) data of the present work: mixers 8/7.2/0.054 (L/D = 0.5, 1.0, 2.0), 8/1.8/0.217 (L/D = 0.5, 1.0, 2.0), 8/3.6/0.109 (L/D = 1.0, 2.0); 3) [3].

By and large, the experimental information obtained in the present work spans a large range of determining parameters, which allows one to use them in combination with the available data in deciding on the optimum geometry of mixers for technological facilities of different application. This conclusion supports, in part, the characteristics of the mixer 8/7.2/0.054 used as a part of the plant for pyrolysis of hydrocarbons [14]. The ratios between the densities and rates of the main flow and the blown-in gas in [14] differed from the corresponding parameters in the present experiments. However, at one and the same values of the LRI parameter, the homogeneity of the flow at the output of the mixer was practical one and the same in both cases.

Conclusions. The characteristics of mixers operating in the regime of colliding jets were investigated in a wide range of determining parameters. The ratio between the rates of the jets and the main flow was varied within the range 0.18–2.82 at a relative length of the mixing chamber L/D = 0.5–1.5, and the relative diameter of the holes was d/D = 0.054–0.217.

It was shown that a high quality-mixing is realized at a short distance from the site of blowing under the conditions of strong interaction of jets (at large values of the LRI parameters h/D). The region of h/D values, where the geometry of the holes weakly influences the degree of homogeneity of the flow at the output of the mixer, was determined.

The results of the present investigation agree with the data obtained by other authors for mixers working in the regime of colliding jets.

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NOTATION

d, diameter of the blowing nozzle, mm; D, diameter of the mixing chamber, mm; f, dimensionless enthalpy (temperature) defect; f', standard deviation; G, gas flow rate, g/sec; h, long-range interaction parameter of a jet, mm; i, enthalpy, kJ/(kg·K); J, momentum, kg/(m·sec^2); K, coefficient; L, length of the mixing chamber, m; n, number of blowing nozzles; r, current radius, mm; R, radius of the mixing chamber, mm; R_1, radius of the undisturbed core of a flow, mm; S, distance between the axes of the nozzles along the circumference, mm; T, temperature, K; w, velocity, m/sec; μ, flow-rate coefficient; ρ, density, kg/m^3. Subscripts: m, main (flow); max, maximum value; j, jet.

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