EVALUATION OF THE POSSIBILITY OF MIXING OF TURBULENT JETS WITH A COMOVING FLOW IN A BOUNDED SPACE BY INTERFERENCE METHODS

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Experimental results showing the possibility of using interference methods for studying mass and heat-transfer processes in the combustion chambers of power generating installations with different configuration are presented.

Burning of fuel in the semienclosed volume of chambers is the most commonly encountered method for organizing combustion. In spite of this, however, the questions of diffusion turbulent combustion, when the components, as a rule, are fed into the chamber without premixing, have not yet been adequately studied [1].

It is well known that one of the main factors determining the intensity of intrachamber processes is the mixing of jets of injected fuel. The most promising methods for studying it are optical methods, in particular, interference methods, since most probe methods are either inapplicable or have extremely limited use. However there are virtually no publications in which the results of a study of heat and mass transfer processes, performed by interference methods, in turbulent jets propagating in the volume of combustion chambers are presented. This can probably be explained primarily by the complexity of the instrumentation, the nonuniqueness of the interpretation of the interferograms when recording optical nonuniformities of a complex shape, which the groups of parallel propagating flames are, and the lack of dependences relating the values of the concentration and temperatures with the refractive indices of the light determined in the analysis of the interferograms. This especially concerns cases when the compositions and starting temperatures of the jet and comoving flow are different.

To evaluate by interference methods the possibility of mixing turbulent jets in chambers and to obtain preliminary results on the range of their applicability we developed and assembled a setup and prepared chambers with flat transparent mirrors and a cylindrical quartz working section. The temperatures and concentrations were calculated from the results of the analysis of the interferograms, referring to one wavelength of light, under the conditions of propagation of jets in a comoving flow with substantially different starting temperatues and molecular weights, based on assumed working dependences that take into account the simultaneous effect of the temperature and concentration on the index of refraction of light.

The interferograms of the jets propagating in the chamber with flat windows were recorded with the help of a polarization interferometer, mounted on the base of the IAB-451 schlieren apparatus and adjusted for full displacement (Fig. 1a). To calculate the refractive index in the zones of the chamber near the wall the temperature was measured at several points along the length, and the gas composition was determined by chromatographic analysis. The volume concentration of the component of the central jet was determined with the help of the expression [2, 3]

$$\varkappa_{O_2} = \frac{n_i - n_B}{n_{O_2} - n_B}. \tag{1}$$

The profiles of the volume concentrations obtained based on the analysis of interferograms of a jet of oxygen gas, which propagates in the comoving flow of a mixture consisting of 20 vol. % helium and 80 vol. % nitrogen in a chamber with a square cross section, are

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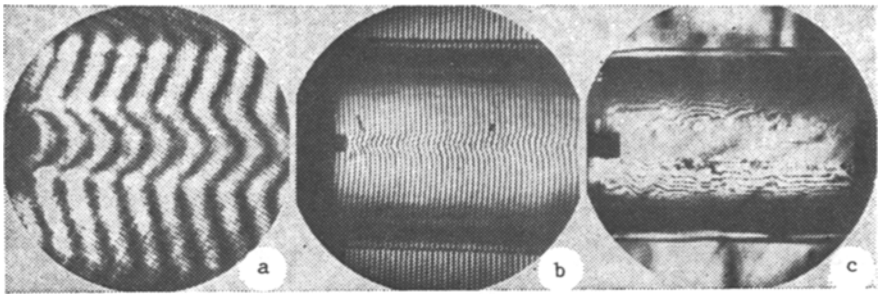

Fig. 1. Interferograms of jets propagating in chambers: a) interferogram of shift, chamber with a square cross section with flat windows; b) holographic interferograms of jets of oxygen gas in a comoving flow in a cylindrical chamber, adjustment for fringes of finite width; c) holographic interferogram of comoving jet around a jet of liquid oxygen in a cylindrical chamber, adjustment for an infinitely wide fringe.

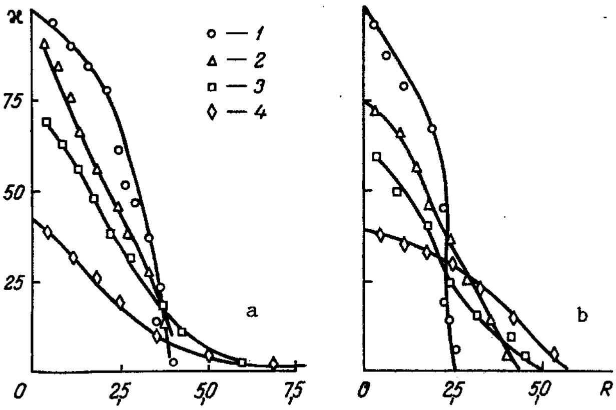

Fig. 2. Distribution of O_2 concentration in the transverse cross section of the flow: a) interferogram of displacement (chamber with a square cross section with flat windows): 1) x/d = 2, 2) 4, 3) 8, 4) 16; b) holographic interferogram (cylindrical quartz chamber): 1) x/d = 1, 2) 4, 3) 6, 4) 11. κ, vol. %; R, $m \cdot 10^{-3}$.

presented in Fig. 2a. The accuracy of the results, evaluated indirectly from the values of the oxygen concentration along the axis of the jet at the nozzle cutoff, equals 3-5%. This value agrees well with the results of [4, 5] and with our data with a special experimental evaluation of the accuracy of the interference method, based on which it was established for axisymmetric jets that the concentrations and temperatures determined by chemical analysis and measured with a thermocouple agree with the analysis of the simultaneously recorded interferograms to within 3-4% [6].

The methods of classical interferometry are, however, of little use for studying the mixing and combustion of gas jets in chambers, which, as a rule, have a cylindrical form [7], while holographic methods permit obtaining interferograms of jets and flames both in flat and cylindrical combustion chambers [8].

The holographic interferograms of jets of oxygen gas in a comoving flow of a mixture of 75 vol. % helium and 25 vol. % nitrogen as well as liquid oxygen in a comoving flow of hydrogen in the volume of a cylindrical chamber with an inner diameter of 50 mm and a wall 10 mm thick, made of quartz glass, were recorded by the double-exposure method. The optical layout of the holographic interferometer employed with the diffusion sprayer is analogous to that presented in [9].

The rates of efflux of the gas jets equalled 100-200 m/sec and that of liquid jets equalled 30-50 m/sec. The holographic interferograms of jets of oxygen gas and liquid oxygen

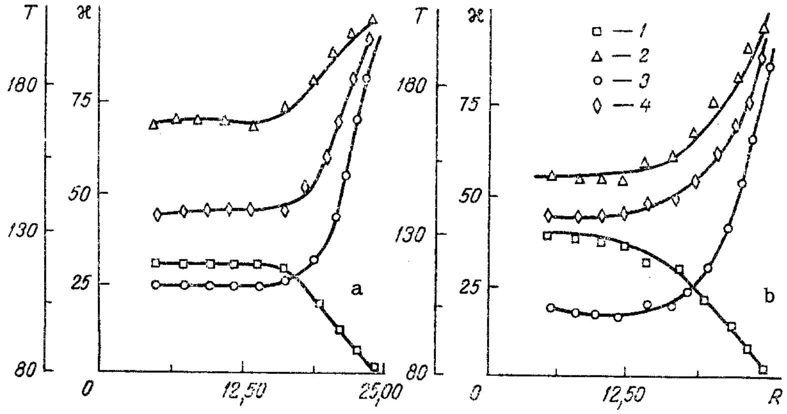

Fig. 3. Temperatures and volume concentrations over the cross sections of the chamber: 1, 2) volume concentrations of oxygen and hydrogen; 3, 4) temperature profiles determined using the expressions (2) and (5), respectively; a) x/d = 0.1; b) 1.5 T, °K.

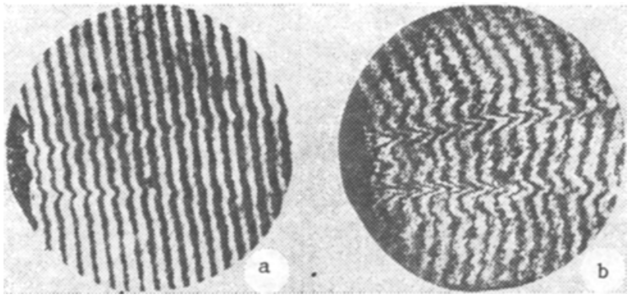

Fig. 4. Interferograms of flames propagating in the chamber: a) without an increase in sensitivity; b) with a fourfold increase in sensitivity.

are presented in Figs. 1b and c. The profiles of the volume concentrations of vaporized oxygen around the jet, calculated from the expression (1), are shown in Fig. 2b.

The profiles of the temperature over the cross section of the chamber in the region of the comoving hydrogen gas flow around the liquid oxygen jet, i.e., in the zone of the mixture of hydrogen and oxygen vapor, were calculated from the results of the analysis of holographic interferograms using both the relation [10]

$$T_i = \frac{(n_{H_2} - 1)\, T_{H_2}}{(n_i - 1)} \tag{2}$$

and the newly proposed relation. The temperature profiles over the cross sections of the combustion chamber are presented in Fig. 3.

An expression taking into account the dependence of the refractive index for light on the temperature and chemical composition can be obtained by writing

$$\varkappa_{O_2} + \varkappa_{H_2} = 1, \tag{3}$$

$$\varkappa_{O_2}\overline{R}_{O_2} + \varkappa_{H_2}\overline{R}_{H_2} = \overline{R}, \tag{4}$$

$$T_i = \frac{P\varkappa_{O_2}\mu C_{pO_2} + P\varkappa_{H_2}\mu C_{pH_2}}{\dfrac{P\varkappa_{O_2}}{T_{O_2}}\mu C_{pO_2} + \dfrac{P\varkappa_{H_2}}{T_{H_2}}\mu C_{pH_2}}. \tag{5}$$

From the solution of these equations we obtain

$$\varkappa_{O_2} = \frac{T_i P_{ref}(n_i - 1)}{P T_{ref}(n_{O_2ref} - n_{H_2ref})} - \frac{n_{H_2ref} - 1}{n_{O_2ref} - n_{H_2ref}}, \tag{6}$$

$$\varkappa_{H_2} = \frac{T_i P_{ref}(n_i - 1)}{P T_{ref}(n_{H_2ref} - n_{O_2ref})} - \frac{n_{O_2ref} - 1}{n_{H_2ref} - n_{O_2ref}}. \tag{7}$$

The temperatures and concentrations calculated from Eqs. (5), (6), and (7) are presented in Fig. 3, and the typical holographic interferograms of burning turbulent gas jets, flowing out of flat nozzles with a pressure of 0.275 kPa in the combustion chamber, are shown in Fig. 4.

Preliminary results show that it is possible to study quantitatively the mass and heat transfer processes accompanying the propagation of gaseous and cryogenic turbulent jets for Reynolds numbers in the range $\sim 3.3 \cdot 10^4 - 2.5 \cdot 10^6$ in a comoving flow in the volume of the chamber by the method of displacement and holographic interferometry.

The proposed dependences permit calculating the temperatures and concentrations of the gas phase of binary media from the analysis of interferograms, formed at one wavelength of light in the case when the indicated parameters change simultaneously.

NOTATION

$\varkappa O_2$, $\varkappa H_2$, volume concentrations of oxygen and hydrogen; n_i, n_B, nO_2, nH_2, refractive indices for light for a mixture of gases in the annular zone of the chamber studied and in the zone of the chamber near the wall, for oxygen and hydrogen; T_i, TO_2, TH_2, temperatures of the gas in the i-th zone of the chamber, oxygen at the outlet from the nozzle and hydrogen at the wall of the chamber; T_{ref}, reference temperature, $T_{ref} = 293°K$; P and P_{ref}, pressure in the chamber at the time of the experiment and the reference pressure, $P_{ref} = 0.98 \cdot 10^5$ Pa; x, axial coordinate of the chamber in the direction of propagation of the oxygen jet; d, diameter of the oxygen nozzle; μC_{pO_2}, μC_{pH_2}, molar heat capacities of oxygen and hydrogen; n_{O_2ref}, n_{H_2ref}, refractive indices of light for oxygen and hydrogen for standard values of the pressure and temperature and $\lambda = 6943$ Å.

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