OPTICAL SOUNDING OF EXHAUST PRODUCTS FROM A SOLID FUEL MODEL ENGINE

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Laser sounding of the exhaust gas flow from a solid fuel model engine near its nozzle exit at three wavelengths (630, 3390 and 10 600 nm) has been performed. Estimation of size, number density, total mass and surface area of aerosol particles per unit volume has been carried out. Presence of ecologically dangerous CO and HCl molecules in the jet far away from the nozzle exit has been determined with an optical–mechanical scanning IR system at the wavelengths of 4800 and 3500 nm for CO and HCl molecules, respectively. The results obtained demonstrate new field of application for the optical research methods and suggest new features for design of gas and plasma flow control systems.

Development of the systems for operative control of the combustion process of the ecologically dangerous substances as well as estimation of the efficiency of neutralizing equipment are now an extremely urgent problems. In this paper potentials of well developed methods of optical monitoring and modern mathematical methods of data processing for such a control are examined.

A model engine operating on metallized fuel based on ammonium perchlorate was used as an air pollution source. Figure 1 presents a diagram of the optical measurements. The jet from a model engine *1* equipped with a solid fuel channel charge *2* was sounded in two regions *A* and *B*. The first region, *A*, is in the exhaust pipe *3* near the nozzle exit. It is observed through the windows *4*. The second one, *B*, is placed two meters from the nozzle exit in a gap between two parts of the exhaust pipe. Laser sounding was performed with a He–Ne laser *5* (λ = 0.63 and 3.39 μm) and CO_2 laser *6* (λ = 10.6 μm). Photomultipliers FÉU–83 *10* and *11* as well as photoresistors *14* and *16* at T = 78 K were used as radiation detectors. The radiation was localized in the given places by the objectives *7*. Separation of radiation from the jet itself was carried out by means of mechanical shutter *8* that modulated laser beams with a frequency of 5 Hz. "Slow" ($\Delta\tau \sim 1$ s) refractive deviation of the scattered laser beam at λ = 3.39 μm was monitored by a thermovision system *17*. A cinerama of nonequilibrium characteristic radiation at λ = 4.8 μm with $\Delta\lambda$ = 0.23 μm (CO molecule) and at λ = 3.5 μm with $\Delta\lambda$ = 0.13 μm (HCl molecule) in the region B was performed using an optical–mechanical scanning system TV–M9 developed in the Institute of Applied and Theoretical Mechanics, Siberian Branch of the Russian Academy of Sciences.[1] Optical elements made of CaF_2 *12*, KRS *13*, and ZnSe *15* were used for radiation splitting. Visible spectrum of the radiation was measured using a glass spectrograph developed by "Carl Zeiss" Company.

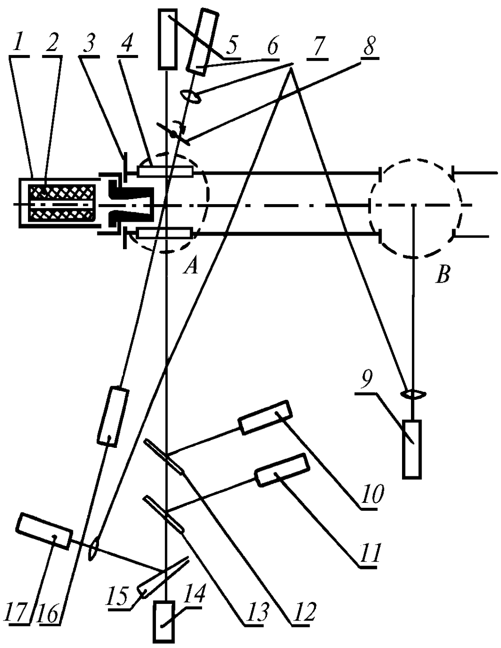

FIG. 1. A diagram of the optical measurements.

The mean values for logarithm of the ratio $I_{0\lambda}/I_\lambda$ ($I_{0\lambda}$ and I_λ are the intensity of the incident and passed light) are summarized in Table I for certain wavelengths and time moments. Analysis of the data obtained shows that within the wavelengths range under investigation the following condition is valid[2]: $q = 2\pi r/\lambda \geq 1$, where r is radius of particles in the condensed phase. In our experiments, light attenuation efficiency factor Q_0 depending on the size of the particles is equal to 1 at λ = 0.63 and 3.39 μm and to 0.3 at λ = 10.6 μm. Relative variations in the temporal behavior of

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absorption at λ = 0.63 and 3.39 μm show that variation of size of particles during combustion process is possible. The characteristic r value in the flow is estimated to be 1–2 μm, the number density of particles N equals approximately $(1-3)\cdot 10^6$ cm^{-3} and the total mass of the aerosol particles M is assumed to be $(1-2)\cdot 10^2$ g. Based on $\ln(I_{0\lambda}/I_\lambda)$ data it is possible to calculate the total surface area of aerosol particles per unit volume. It is found to be S = 0.2 cm^{-1}. It should be pointed out that this S value which was determined most accurately in our measurements is of great importance for evaluation of the influence of the aerosol particles on catalytic reactions in the flow and on reactions of neutralization of the exhaust products.

TABLE I.

No.	τ, s	$\ln(I_{0\lambda}/I_\lambda)$ for λ (μm)		
		0.63	3.39	10.6
1	0.25	0.59	0.48	0.15
2	0.5	0.26	0.48	–
3	1.0	0.38	0.47	0.15
4	1.5	0.63	0.47	0.15
5	2.0	0.76	0.32	0.11
6	2.5	0.18	0.38	0.039

Figure 2 shows radiation energy distribution over the cross section of a He–Ne laser beam (λ = 3.39 μm) obtained with a thermovision system, a_1 corresponds to the incident beam, a_2 corresponds to the beam passed through the jet. The intensity gradation scale is presented in Fig. 2 in relative units. Beam deviation caused by refraction was chaotic, and its value did not exceed 2 mm. Therefore, the gas density gradients are negligible in the sounded region for distances of 10 mm. The beam deviation affects though only slightly the accuracy of the absorption measurements. The beam expansion results from diffraction on large particles and turbulent fluctuations.

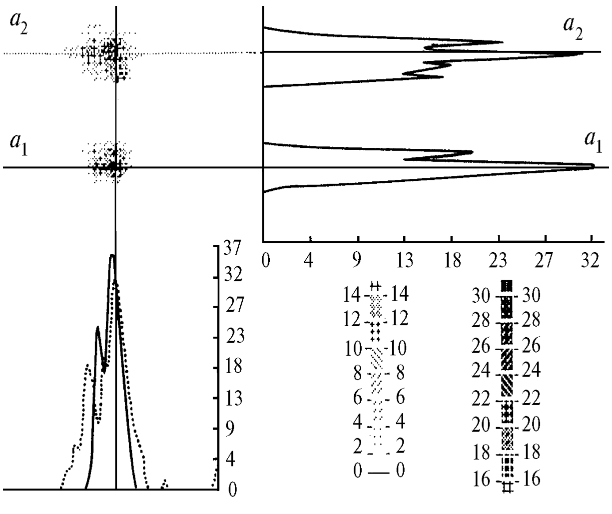

FIG. 2. Radiation energy distribution over the beam cross section at λ = 3.39 μm. *Here* a_1 *corresponds to incident beam and* a_2 *corresponds to a beam passed through the jet.*

Thermovision measurements of the ecologically dangerous gaseous components were carried out near the characteristic bands of CO and HCl molecules. The radiation intensity of the products of combustion as a function of time in the region B (Fig. 1) is shown in Fig. 3 for CO molecules and in Fig. 4 for HCl molecules. Figures 3a and 4a demonstrate the axial and peripheral dynamics of the emission from the jet flow; Figs. 3b and 4b present the intensity distribution over the cross section at different moments of time. Spatiotemporal cross sections and corresponding curves are shown by the same lines.

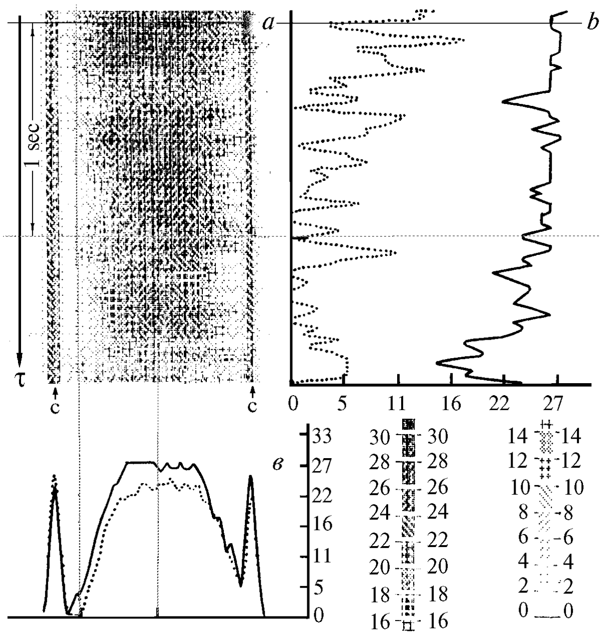

FIG. 3. Temporal behavior of the radiation intensity distribution over the beam cross section near CO *molecule band* (λ = 4.8 μm) *far away from the nozzle exit; m is thermal mark.*

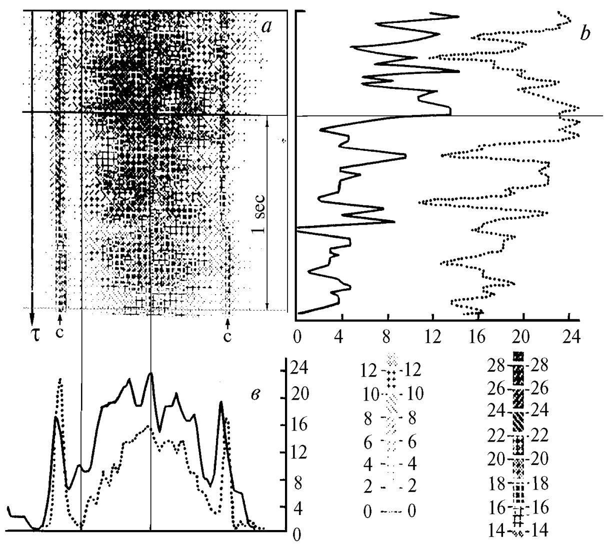

FIG. 4. Temporal behavior of the radiation intensity distribution over the beam cross section near the HCl *molecule band* (λ = 3.5 μm) *far away from the nozzle exit; m is thermal mark.*

The experiments have shown the following.

1. At small distances from the nozzle exit the jet radiation spectrum in the visible range (0.3–0.7 μm) is close to the equilibrium continuous spectrum except for resonance Na lines.

2. At large distances from the nozzle exit (~ 50 bores) the intensity of the characteristic IR radiation at certain wavelengths exceeds by more than one order of magnitude the intensity of the equilibrium continuous spectrum. The continuous spectrum is caused by the presence of solid phase.

3. The jet is transparent for IR with $\lambda > 10$ μm except for discrete absorption bands. Shorter wavelength absorption is caused by interaction with microparticles.

These results are of great importance for selection of the specific optical research methods and for design of the systems of gas and plasma flow control.

REFERENCES

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2. V.K. Baev, S.S. Vorontsov, R.I. Soloukhin, and P.K. Tret'yakov, in: *Gas–Phase Flame Structure,* Institute of Theoretical and Applied Mechanics, Siberian Branch of the Russian Academy of Sciences, Novosibirsk (1984), pp. 112–122.