EFFECT OF CO_2 LASER RADIATION ON HYDROCARBON FLAME

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Presently, a considerable study is being given to various methods to control combustion using electric discharges, laser radiation, control of flow quantities, etc. [1-3]. The purpose of the present work was to investigate the mechanisms of action of focused pulsed-periodic CO_2-laser radiation and optical pulsating discharge (OPD) on hydrocarbon-air pre-mixed combustion and pre-flame processes. The problem was solved by establishing the relation between laser radiation characteristics, fuel properties, and flow quantities and integral characteristics of the process, namely, propagation velocities of laminar and turbulent flames, flame structure and stability, spectrally integrated CH, C_2, and OH band emission, and ignition dynamics under laser initiation. In the experiments, several combustion schemes were employed [4]. Results concerning the influence of intense pulsed-periodic CO_2-laser radiation and OPD on the combustion of mixtures of propane, spirit and benzene with air in laminar and turbulent regimes are reported.

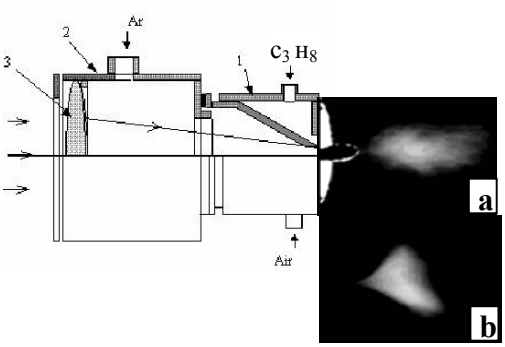


Fig. 1. Experimental setup.
a – propane flame stabilized by OPD,
b – stabilization at the focusing zone

To examine the effect of OPD and laser radiation on the laminar and turbulent velocities of hydrogen and hydrocarbon fuels, we used an experimental facility schematically shown in Fig. 1. The fuel is being mixed with air in mixing chamber 1. To facilitate the breakdown, an argon jet flow is fed along the axis. The jet is about 5 mm in diameter. Radiation is focused by KCl lens 3 with a focal length of 280 mm. It was found that, within the measurement accuracy, the optical pulsating discharge has no effect on the turbulent-flame propagation velocity. Without OPD, the rate of turbulent combustion increases due to temperature preconditioning of the mixture by absorbed laser radiation [4]. Regimes with flame stabilization by a temperature anomaly in the laser radiation focus zone were observed.

Laminar combustion was examined for tube edge-stabilized propane flames. In these experiments, the burner body was a quartz tube 13.5 mm in diameter. The Reynolds number was varied in the interval 400 – 1200, and the composition of the mixture, in the interval $\alpha = 0.8 \div 4.1$. Laminar and turbulent flames were examined in the range of Reynolds numbers $Re = 1500 \div 4600$ on a setup with flame stabilization by a 5 mm diameter central body of 30 mm diameter nozzle. On these setups, it was possible to preheat the mixture to a temperature of 300°C and organize fuel evaporation. In all experiments, the minimum diameter of the focused laser beam was d = 1.3 mm. The time-average incident radiation power $W = (0.07 \div 1.2) \times 10^5$ W/cm^2 was almost uniform in the interaction zone. The monitored quantities were the mean laser output power, the repetition frequency of the laser pulses, the relative pulse duration and, in some cases, the waveform of the pulses. CCD cameras were used to register the shape and intensity of the emission due to intermediate reaction products, CH and C_2 radicals. To register the OH band emission in the ultraviolet portion of the spectra, an intensity amplifier was used, coupled with a CCD chamber. The photographs were used to examine the shape of the flames and calculate the laminar and turbulent burning rates and spectrally integrated emission of CH, C_2, and OH.

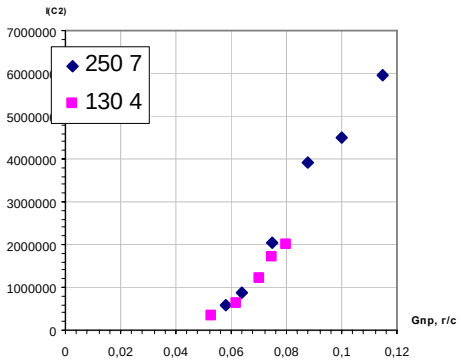


Fig. 2.

From the measurements, we found that, within the measurement accuracy, the initial temperature of the mixture had no effect on the integral CH, C_2 and OH emission from the laminar flame in the temperature interval 20÷250°C. Figure 2 exemplifies the relative C_2 emission intensity against the mass rate of the propane flow for two temperatures and velocities of the mixture (t=250°C, U_o=7.0 m/sec and t=130°C, U_o=4.0 m/sec). Under laser irradiation, these intensities were found to remain unchanged despite of a dramatic change in the flame shape. The change in the flame shape was due to variation of the rate of combustion in the thermal wake behind the zone where the laser radiation interacted with the fuel mixture. Figure 3 shows the distribution of temperature in the thermal wake measured by a thermocouple in one of the regimes examined. The measured temperatures agree well with the temperatures predicted by evaluating the degree of heating of the mixture by the absorbed laser radiation.

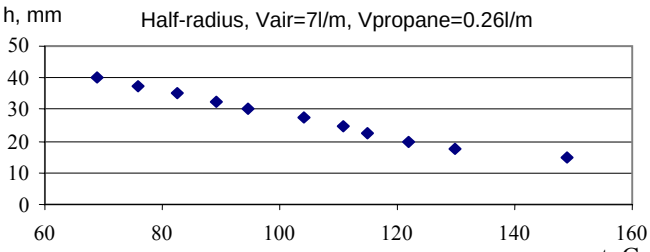
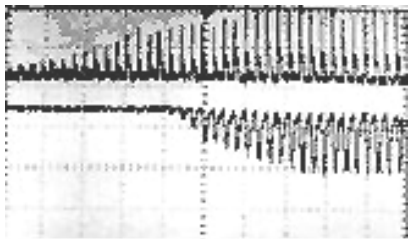


Fig. 3. Temperature in the thermal wake

Using a radiometer equipped with a multiplier photocell that registered the time evolution of the space-integral emission due to radicals, we examined the ignition dynamics of mixtures of hydrocarbon fuels with air at laser initiation. In the entire process, three characteristic stages were revealed: 1. "Heating" of a vibrational level by the absorbed laser energy; 2. Formation of a hot spot; 3. Flame front formation (flame development). The ignition dynamics depended on the type of the fuel and on the composition and velocity of the mixture. Figure 4 shows the dynamics for a lean spirit-air mixture under laser-pulse energy insufficient for ignition. For rich conditions, the effect due to the additional energy input was either weak or absent, the degree of manifestation of the effect being dependent on the type of fuel.



To summarize, we examined the influence of intense pulsed-periodic CO_2-laser radiation and laser breakdown on the ignition and combustion of hydrocarbon fuel-air mixtures in a broad range of laser-radiation parameters, and composition and initial temperature of the mixture. It is shown that the experimentally observed effects concerning the influence of laser radiation on the combustion process can be explained assuming the thermal mechanism. The ignition by laser radiation is governed by a more complex mechanism that calls for further study.

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References

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