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IGNITION OF A FUEL-AIR MIXTURE WITH A HIGH-SPEED PLASMA JET

V. V. Afanas'ev, A. K. Kuz'min,
S. A. Abrukov, V. N. Podymov, and
S. V. Il'in

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The conditions of ignition and the velocities of propagation of a flame along a tube in combustible mixtures prepared in advance upon ignition with a spark and a high-speed pulsed plasma jet are experimentally investigated.

Investigations of new prospective methods of ignition of fuel-air mixtures are of great scientific and practical importance, for example, in the field of the fire and explosion safety of technological processes connected with mining, transportation, and processing of combustible minerals. An increase in the volume rate of burn-up of low-calorie fuels is also of practical interest. It is known from data of [1–3] that combustion is intensified if a shock wave is formed ahead of the flame front. No shock wave is formed in low-calorie combustible mixtures, and therefore the authors of [3] proposed forming it artificially by means of a rapidly burning methane-oxygen mixture in a precombustion chamber.

In the present work the conditions of ignition and the velocities of propagation of flame are studied in a premixed methane-air charge in a semiclosed tube upon ignition at the closed end of the tube with a point spark and a high-speed pulsed plasma jet flowing out of a pulsed plasma accelerator.

Experiments were carried out using the experimental setup presented in Fig. 1. The units of the setup are as follows: semiclosed tube 1, electromagnetic plasma accelerator 2, instrumentation 3–6, and the system for preparation of the combustible mixture 7–12. The tube 1 was made of a thick-walled steel blank with an inner diameter of 60 mm in the form of three separate sections with a total length of 3.75 m. A propane-air charge was prepared using the dynamic method. To do this, propane and air were fed in the required proportion from the cylinders 7 and 8 through reducers to the mixer 9. Then the mixture was fed through the electrohydraulic valve 10 to the tube 1. The combustible mixture composition was monitored using a Rayleigh interferometer 11 with an accuracy up to 0.1%. The valves 10 and 12 served to shut off the feeding of fuel to the setup in the course of the experiments.

In each of the sections of the tube 1, recesses were made for velocity measurements by means of ionization sensors or photodiodes. In order to reduce the influence of noise from the electromagnetic plasma accelerator, a voltage of 500 V was applied to the ionization sensors from the high-voltage power supply 5 via the matching device 4. The signal from the ionization sensors was applied to the time interval analyzer 6.

The electromagnetic plasma accelerator 2, which is a coaxial pulsed plasmatron with a tapered unit, was fixed at the open end of the tube. The plasmatron was connected to a bank of high-voltage capacitors with a total capacity of 31 μF and a working voltage of 20 kV. The plasmotron was started with an auxiliary spark using an additional ignition electrode.

The combustible mixture was ignited using a high-speed plasmoid or a high-voltage point spark 13 at the closed end of the tube. The mean velocity of the plasma outflow from the outlet electrode, estimated using high-speed film, is about 600 m/sec in the first $2 \cdot 10^4$ sec and then it decreases rapidly as the plasma moves away from the outlet. The plasma is accelerated up to Mach numbers equal to several units due to gasodynamic pressure and electromagnetic forces resulting from the interaction of the radial component of the current with the azimuthal component of its own magnetic field, which appears at the instant of discharge of the storage capacitors.

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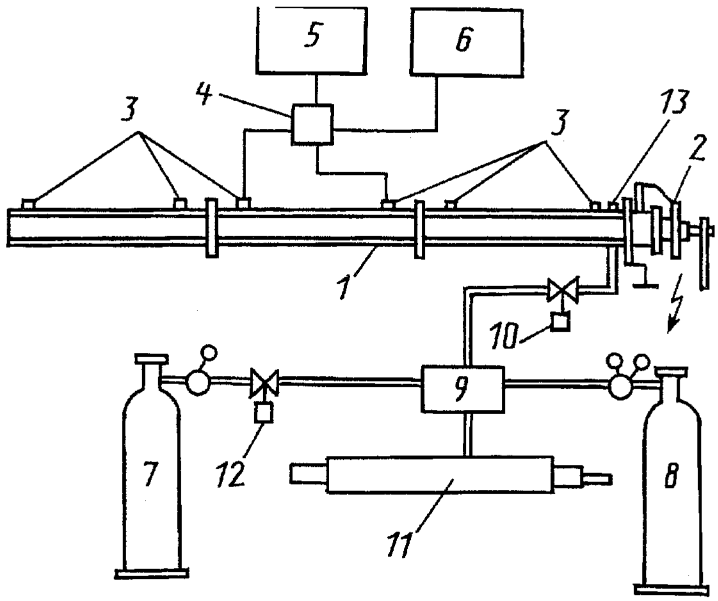

Fig. 1. Schematic diagram of the experimental setup.

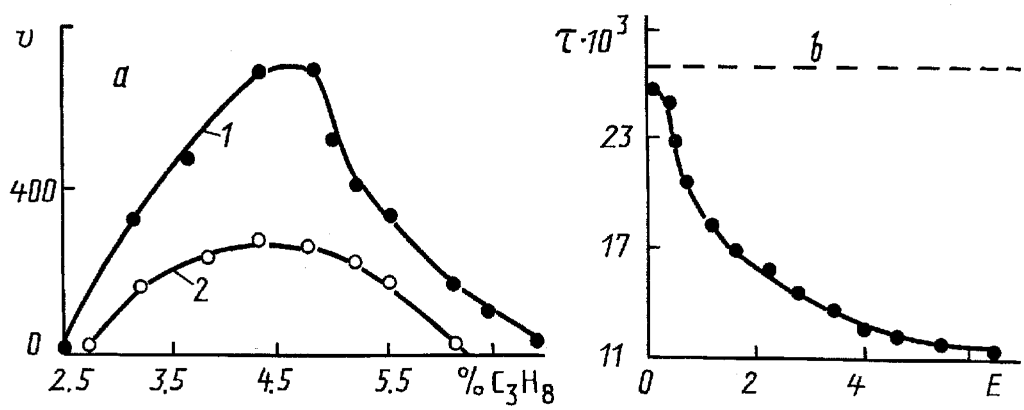

Fig. 2. Dependence of the flame propagation velocity on the combustible mixture composition (a) and dependence of the time for traversing the tube length on the electric energy stored in the capacitors (b). τ, sec; E, kJ; v, m/sec.

The dependence of the propagation velocity of the flame front at the last (third) section on the composition of the combustible mixture is presented in Fig. 2a. Curve 1 is obtained upon ignition of the combustible mixture with the high-speed pulsed plasma jet. The electric energy stored in the capacitors is equal to 3 kJ. Curve 2 is obtained upon ignition with the spark. From the figure we notice that within the studied range of fuel compositions the propagation velocity of the flame is more than twice that in ignition with the spark, whereas at the concentration limits, especially at the upper one, the velocity is at least tenfold greater. We also note the widening of the concentration limits of ignition and propagation of the flame. For example, the upper concentration limit is widened by almost 1%.

The increase in the flame propagation velocity is attributable to the fact that the combustible mixture is ignited with the plasma accelerator not at a point but in a volume whose dimensions are determined by the dimensions of the plasmoid, i.e., by the energy stored in the capacitors. For example, at an energy of 3 kJ the plasmoid is formed into a sphere about 10 cm in diameter. In addition, an initiating action can also be exerted by the shock wave formed by the pulsed plasma accelerator as a result of compression and heating of the combustible mixture ahead of the flame front [1–4].

An influence of active particles and ions, e.g., electrons and nitrogen oxides, formed as a result of the powerful electric discharge, on the rate of chemical reactions within the combustion wave is also possible [5].

The dependence of the time for the flame front to traverse the tube length through a mixture of 5% C_3H_8 + air on the electric energy stored in the capacitors is presented in Fig. 2b. In this case the energy was varied by varying the voltage rather than the capacitance. From the figure it is seen that the time for the flame to traverse the tube length decreases monotonically with increase in energy, approaching some constant value at 6 kJ. There is little point in increasing the energy further since the propagation velocity of the flame along the tube approaches a stationary regime. At the same time a decrease in the energy stored in the capacitors to 0.2 kJ results in a minor difference between the propagation times of the flame front upon ignition with the plasma accelerator and the spark (dashed line). A further decrease in the energy in the capacitors leads to start-up failure of the plasmatron.

It was noted in the course of the experiments that the initiation of the pulsed discharge in the plasma accelerator depends strongly on the combustible mixture composition. Upon filling the tube with the combustible mixture the volume between the rod and coaxial electrodes of the plasmatron was filled simultaneously. This circumstance resulted in a substantial decrease in the voltage of spontaneous mixture ignition and discharge initiation compared to air. In this case the voltage decrease is directly proportional to the propane content in the mixture. Local ignition of the combustible mixture inside the plasmatron at the sites with increased electric field strength, e.g., as a result of a corona discharge, constitutes a possible reason for spontaneous discharge initiation in the pulsed plasmatron and ignition of the combustible mixture in the tube. This circumstance precluded raising the voltage on the capacitors above 10 kV due to the spontaneous discharge and ignition of the combustible mixture in the tube. Moreover, in the course of the discharge a black powder with a dispersivity up to 100 μm is formed between the electrodes. X-ray diffraction analysis has shown that iron carbide is formed predominantly. A possible reason for iron carbide synthesis is the combining reaction of iron evaporated from the electrodes with free carbon of propane in the course of the discharge.

Thus, it follows from the experimental data discussed that the ignition of a fuel-air mixture with a high-speed plasma jet intensifies substantially the combustion process and widens the concentration limits of flame propagation along the combustible mixture, and therefore it can be used in the field of fire and explosion safety and in various combustion devices.

REFERENCES

1. G. D. Salamandra, in: Physical Gasodynamics, Heat Transfer , and Thermodynamics of High-Temperature Gases [in Russian], Moscow (1962), pp. 194-198.
2. S. M. Kogarko, Zh. Tekh. Fiz., **30**, No. 1, 65-70 (1960).
3. N. I. Mayorov and I. K. Fedoseeva, Fiz. Goren. Vzryva, No. 3, 42-44 (1988).
4. G. D. Salamandra, Photographic Methods of Studying Fast Processes [in Russian], Moscow (1974).
5. I. Felix and F. R. S. Weinberg, Advanced Combustion Methods, N. Y. (1986).