Investigation of Plasma Bunch for Artificial Ignition of Fuel in Supersonic Flow

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During recent decades, the combustion processes in a supersonic stream are studied intensively. The purpose of these investigations is the production of a supersonic combustion chamber working on the hydrogen and hydrocarbon fuels. The problem of the stable and uniform ignition and effective combustion of a gas mixture in super- and hypersonic flows is critical important from both scientific and technological point of view. Due to the interest to formation effect on plasma ignition of fuel at the high-velocity cold and hot flows, the different methods of artificial ignition are considered. Main goal of these investigations were to provide relatively cheap and reliable ignition and fuel combustion in supersonic flow and research of physical aspects and problems of the proposed methods, their operation, performance in supersonic fuel/air reacting flow.

The two mechanisms, by which a discharge can influence on a gas, should be taken into account when using a discharge to initiate ignition and combustion. For discharges resulting in the formation of an equilibrium (or nearly equilibrium) plasma (e.g., spark and arcs), the main factor that reduces the delay time of ignition is local heating of gas and, accordingly, the increase in rate of thermal dissociation. In case of non-equilibrium plasma, the main mechanism initiating chain reactions consists in dissociation and excitation of molecules by electron-impact.

The paper presents the results of investigation of the initiated combustion of the reagents in a supersonic flow under the action of plasma. In this work it is offered to use the high-speed high-enthalpy plasma clot for the mixture ignition generated by a railgun, which should provide joint plasma and thermal (shock - wave) action on the flow along overall volume of area of fuel injection.

Test of combustor were performed at the hotshot wind tunnel IT-302M with arc heating in the attached pipeline mode. Such mode of investigation allows an effective use of the advantages of the hotshot wind tunnel as a source of a high-enthalpy test gas (air). Model of combustor was tested at the following conditions at the duct entrance: Mach numbers M_{en}=3-5, total temperature T_t=1500-3000K, static pressure P_{en}=0.08-0.4MPa, and fuel-air equivalent ratio varied from 0.25 to 1.4.

During the tests next parameters were measured: the total flow parameters in first and second prechambers; air and fuel flow rates; distributions of static pressure and heat flux in the model channel. At the same time registration of OH- or CH-radical radiation and flow visualization in visible range were carried out. The camera with frequency of about 1000 frames per second was used for registration of flame images. This allows one to obtain distribution over the combustion chamber with identification of the position of reaction regions.

Prior to the experiments with the combustion initiation in high speed flow, the plasma bunch characteristics were studied in gas. The characteristics of the plasma bunch obtained by means of such railgun, were studied earlier. If natural gas is used as the plasma-forming gas, speed of the plasma bunch can reach 10 km/s. Injected into gas the plasma bunch forms a toroidal vortex, in which the mixing of plasma with cold gas occurs during 10÷30 mks. The dimension of mixing region amounts to about 10 cm.

Results of investigation of methane ignition in the channel at the Mach number 3 have shown that application of railgun leads to ignition of fuel-air mixture.

Application of the combined scheme of fuel injection (before a cavity and in a cavity) was not accompanied by essential increase in pressure and flame propagation along overall channel.

Research of hydrogen ignition by means of railgun has shown possibility of initiation of intensive combustion. Comparison of visualization of a flame at hydrogen combustion with visualization at the use as fuel of natural gas, demonstrates qualitative and quantitative difference in intensity and duration of a luminescence. At ignition of natural gas the bright luminescence was observed only in a cavity.

Within the scope of proposed mathematical model the reacting system was considered in three-temperature approach, in which individual temperature groups were the following: "cold" particles include components of an initial methane-air mixture and products of its decomposition, "hot” particles" include atoms and ions of the injected plasma formation and electrons.

As the kinetic scheme of the combustion of a methane-air mix was chosen the famous scheme. Some insignificant reactions with participation of complex substances have been removed and certain reactions with participation of "hot" particles and electronic components have been added. The upper bound of a confidence interval of temperatures for the majority of values of elementary reactions speeds constants for the given scheme does not exceed 3000-4000K This condition has defined level of admissible temperatures at calculation of equilibrium structure of injected plasma of methane. Owing to small concentration of the charged particles, all reactions, connected with their interaction, are omitted, except for the reactions of ionization and recombination, which lead to temperature change of electrons, and also to the reactions where an ion and electron are third particle.

For the purpose of definition of the model completeness of kinetic mechanisms, calculations of participation of "hot" particles have been carried out under the full kinetic scheme and under the truncated kinetic scheme.

If to take into consideration influence of hot particles (the full scheme), there is a monotonous decrease in temperature up to level at which combustion becomes impossible. This result allows finding out the processes suppressing initiation of combustion at artificial ignition. Choosing as plasma-forming gas other substances, it is possible to try to exclude the processes suppressing combustion.

Conclusion. Despite of short-duration process of the combustion and a low level of a heat release, the possibility of ignition of hydrocarbon fuels has been confirmed at the high speed of the flow in channel. The suggested mathematical model has allowed to find out the nature and conditions of ignition, and to understand the reasons of the fast discontinuance of combustion process at artificial initiation.

At plasma initiation of combustion, the kinetic mechanism is very sensitive to the model completeness of elementary reactions with participation of components of plasma and its elementary composition. Dynamics of process of the combustion initiation appreciably was formed by the initial stage, in which reactions with participation of "hot" particles are prevailing. Probably, at appropriate selection of plasma-forming gas, combustion initiation can occur. For example, if plasma of noble gas is used, it is possible to realize practically the conditions of the truncated scheme of calculation, and it will allow to suppress the return reactions caused by presence of "hot" particles.