MODELING OF THE DIFFUSION FLAME STABILIZATION BY PLASMA

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Technical applications of combustion processes often require a low emission of toxic compounds and a stable operation at the near blow-off regime. One of the ways of the lean flame stabilization is a nonequilibrium plasma discharge action. Understanding of the mechanisms of the flame activation by plasma is particularly relevant to the use of plasma to enhance the bluff body flame stabilization in the after-burner augmentors of an aircraft engine [1]. As a main promoter of the lean combustion process nonequilibrium plasma created by the nanosecond pulsed discharge is often used [2]. For example in [3], it was shown that the pulsed repetitive discharge can significantly improve the diffusion flame stability, extending the stability limit to the temperatures where there is no flame in the discharge absence.

Considering a turbulent diffusion flame it is supposed originally, that a turbulence-chemistry interaction is controlled by the turbulent mixing, and as a consequence, a chemical reaction rate is inverse proportional to the large-eddy mixing scale time. At this case it is not well understood yet what the main mechanism of the discharge plasma influence on the flame stabilization is. Depending on the nanosecond pulsed discharge mode such as a diffusion mode and a filamentary one, we could underline as possible effects the following: thermal heating of the gas by the discharge plasma (only for a discharge in the filamentary form), the enhancement of the dissociation level of fuel molecules, a production of active radicals in the discharge zone, influence of energy saved in the vibrational degrees of freedom on the local heating, the localized turbulence generation and the local mixing intensification by the high-energy deposition (only for a discharge in the filamentary form).

We consider a turbulent methane jet discharging into a quiescent air assuming additional thermal, non-thermal and chemical energy inputs by the nanosecond pulsed discharge. The considered problem was 2D and axisymmetric with the cylindrical inlet for a fuel and the cylindrical bluff body for the flame stabilization. A plasma input was calculated using 1D model of the nanosecond pulsed discharge [4]. It was supposed that a methane-air mixture consists of 53 components according to the GRI 3.0 mechanism of the hydrocarbons combustion. Main details of the calculation procedure are as follows. The stiff source term was treated by the fractional step procedure (splitting scheme). Chemistry was solved for the homogeneous system using explicit Euler method. For the non-reactive flow the finite volume scheme was used. The gas temperature was calculated by the Newton iteration method. Modified Scharfetter-Gummel exponential scheme for the electric drift terms and MUSCLE-Hancock schemes of the second order accuracy for the convective terms and second order central differences scheme for the diffusion terms have been used. Thomas algorithm combined with the iteration method and trapezium method was used to calculate integrals in Boltzmann equation using the uniform grid in the electron energy space. Turbulence was modeled by the standard $k-\varepsilon$ model of turbulence. Chemicaleffects of the plasma discharge were included in the model by the periodical initial conditions.

The closure for the chemical term was formulated in the frame of the modified eddy-dissipation model. As main parameters of the level of plasma nonequilibrium such parameters as $\varsigma_V = (T_V - T_0)/T_0$ and $\varsigma_e = (T_e^0 - T_0)/T_e^0$ were used, where T_0, T_e^0, T_V are the characteristic values of translational, electronic and vibrational temperatures respectively. As a part of the discharge energy goes to the vibrational degrees of freedom the model additionally includes an equation for the vibrational energy E_ν in the form, which is valid after the discharge action

$$\frac{\partial E_\nu}{\partial t} + \frac{1}{r}\left(\frac{\partial}{\partial r}(rE_\nu u)\right) = \frac{1}{r}\frac{\partial}{\partial r}(rD_\nu \frac{\partial}{\partial r}E_\nu) - \frac{E_\nu(T_V) - E_0(T)}{\tau_{VT}}$$

where τ_{VT} is the translational-vibrational relaxation time.

It was obtained that for the considered lean methane-air mixture with equivalence ratio $0.5 \le \Phi \le 0.8$ a nonequilibrium parameter equals to $\varsigma_V \cong 0.3 \div 0.7$ for a discharge in the diffusion mode and $\varsigma_V \cong 1.5 \div 3.5$ for a discharge in the filamentary form. It was shown that the main effect of the nanosecond pulsed discharge plasma on the flame stabilization is connected with a flame sustainability due to a periodic ignition by the plasma modeled by the periodic external source. An effect of thelocalized turbulence generation and mixing intensification were insignificant due to a low discharge power.

LITERATURE

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PARTIALLY PREMIXED COMBUSTION SUPPORTED BY PLASMA

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