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 $0.5\le\Phi\le0.8$ a nonequilibrium parameter equals to $\varsigma_V\cong0.3\div0.7$ for a discharge in the diffusion mode and $\varsigma_V\cong1.5\div3.5$ 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.

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PARTIALLY PREMIXED COMBUSTION SUPPORTED BY PLASMA

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There are a lot of papers devoted to the problems of combustion assisted by the different discharges plasma. A review of the recent experimental data at this area is presented in [1]. The great scientific interest to these problems is caused by a necessity to organize a clean combustion process with a low level of toxic emissions. One of the ways of the problem solution is an organization of the ultra-lean mixture combustion. In that case additionally to the difficult problem of the ultra-lean mixture ignition a problem of the flame stabilization appeared. A corresponding energy input by the discharge plasma in the flame recirculation zone can stabilize the flame as it was shown in [2]. To create a plasma area authors in [2] used a nanosecond pulsed discharge. It is well known that this discharge creates a nonequilibrium plasma due to a very short pulse duration. So in that case a question is what the main effect of the formed discharge plasma on the turbulent combustion process and its stabilization. In the experiments it is very difficult to separate thermal, chemical and non-thermal effects of the discharge plasma so the best way to examine that is a mathematical modeling.

We consider a premixed jet of propane-air mixture discharging into a quiescent atmosphere with an additional energy input by the nanosecond pulsed discharge. To test the proposed model the problem geometry was chosen coinciding with the burner geometry in the experiments [2] with the cylindrical gas mixture inlet and the cylindrical bluff body for the flame stabilization. A source term in the energy equation that models a plasma input was calculated using 1D model of the nanosecond pulsed discharge [3] and then tabulated as a function of the time and space. To model turbulent combustion we used an assumption of the very rapid chemical kinetics in the flame. The mixture flow was considered in the near chemical equilibrium condition and position of the flame front was determined based on the transport equation for the premixed reaction-progress variable. A progress variable was defined as a normalized sum of product species $c = \sum_{i=1}^{n} Y_i \Big/ \sum_{i=1}^{n} Y_{i,ad}$, where Y_i is the mass fraction of species i, $Y_{i,ad}$ is the mass fraction of species i after adiabatic combustion. As a closure for the chemical reaction rate in the premixed turbulent combustion is still challenging, a choice of the closure model for the considered case of the V-shaped flame was chosen in the frame of the eddy-dissipation model, as for the diffusion combustion.

It was shown that this assumption is quite satisfactory and could describe the experimental flame pattern with different flame regimes because of the intermittency factor $f = c \cdot (1 - c)$. Ahead of the flame front it was supposed that a chemical reaction rate was controlled by the mixing process and turbulence, so all the species distribution could be derived from the calculated Zeldovich variable (the mixture fraction) distribution. It was also supposed that a propane-air mixture consists of 53 components according to the GRI 3.0 mechanism of the hydrocarbons combustion. It should be noted that in the recirculation zone the stretch effect of the flame could be significant so the source term in the progress variable equation was additionally multiplied by a stretch factor in the form of the complementary error function for the turbulent dissipation rate distribution. Parameters of the nanosecond pulsed discharge were as follows: a pulse width -10 ns, an interelectrode gap – 3 mm, a maximum voltage – 10 kV. We considered a lean propane-air mixture with equivalence ratio $0.5 \le \Phi \le 0.8$.

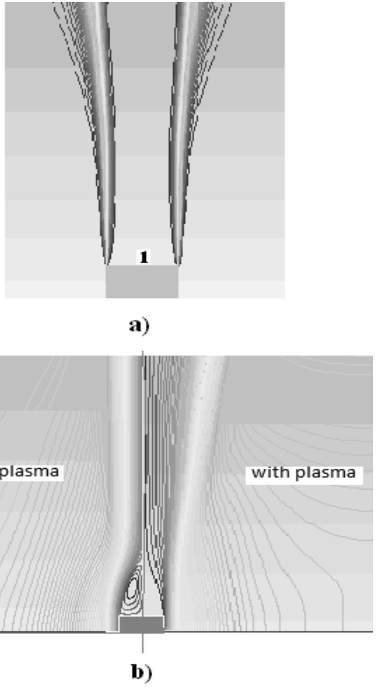

Fig.1. V-shaped flame stabilized by plasma: a)a progress variable distribution for the case of $Re = 15000$, b)stream lines at $Re = 18600$ without plasma (flame extinction) and with plasma(flame stabilization).

It was obtained that for the considered range of the Re number $5 \cdot 10^3 \le Re \le 18 \cdot 10^3$ the V-shaped flame is formed, with the transition to the flame extinction at high $Re \ge 18600$ and for the lean mixture limit. It was also shown that the V –shaped flame can be stabilized by the nanosecond plasma discharge, if the discharge plasma was located in the recirculation zone under the bluff body (zone 1 in the Fig.1a) with a very low power input. Main effect of the formed plasma column is thermal and can be modeled as a heat source with the source term intensity, which is proportional to the discharge power averaged on the plasma volume from the experimental data.

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PROCEDURES FOR ASSESSING THE CUMULATIVE DAMAGE AND EVALUATION OF THE REMAINING LIFE OF STEEL FURNACES TUBES OPERATING IN OIL REFINERIES

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The paper analyses the main degradation mechanisms of pipes used in furnaces from refineries and petrochemical plants and suggests a procedure for determining the cumulative damage of these pipes, given their long use in fluctuating pressure and temperature regimes according to the needs of the technological processes served by the furnaces. It is established that the assessments for furnace pipes in refineries and petrochemical plants must be made considering the effects of creep phenomenon, combined with those of cyclic loading (fatigue) and with the action of the fluid that flows through pipes (which can cause superficial carburization on the inside surface of the pipes) and with the working environment inside the furnace (which can cause oxidation and superficial decarburization of the pipes). The proposed methods for examining and checking the pipes during periodic inspections of the furnaces are also indicated together with the ways these results may be used to increase the confidence level of the information provided in the procedure proposed by the authors for continuous monitoring of the pipes in use.

Furnace pipes in petroleum refineries and technological plants for hydrocarbons processing – PRFP are subject to severe thermal regimes during operation. In refineries, the working temperatures of these pipes reach 120...130 °C in desalination installations and can go up to 350...550 °C in atmospheric and vacuum distillation units and may be even higher – 500...700 °C – in thermal cracking plants and 650... 850 °C in pyrolysis installations. Furthermore, mechanical stresses of high intensity, variable in time, are generated during operation within PRFP, due to the action of transmitted fluids pressure, mass loads (weight of pipe and transported fluids) and frequent temperature fluctuations. In addition, due to the interaction with transmitted fluids and with the atmosphere inside the furnaces, the PRFP suffer (in their superficial layers or in all their section) significant changes of chemical composition, metallurgical structure and physical and mechanical properties

In time, due to the working conditions, the PRFP undergo a damage process (they have limited durability) and must be replaced periodically.

The main degradation phenomenon for PRFP is creep, but fatigue damage (due to cyclic stress) and also damage caused by the interaction with fluids circulating inside the pipes and the atmosphere in furnaces can have substantial effects on the endurance of the pipes.

Depending on the working conditions, the PRFP can be made from plain steels, low, medium or high alloy steels, or from superalloys; generally, (seamless) rolled pipes are used, and also centrifugal cast pipes (austenitic stainless steel Cr – Ni type) are used for some other applications such as pyrolysis furnaces. The main materials used for PRFP will be briefly presented and characterized in the paper.

Rational use of PRFP involves continuous monitoring of their technical status, by tracking their working regime (temperature t_s and pressure p_s) and by assessing cumulative damage and remaining life, applying the procedures proposed in this paper.

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АНАЛІЗ ТА ОЦІНКА ЕНЕРГІЇ ХВИЛЬОВОГО РУХУ В ДВОШАРОВІЙ РІДИНІ З ВІЛЬНОЮ ПОВЕРХНЕЮ

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Фізико-математичне моделювання шаруватих рідких систем і чисельний та фізичний аналіз отриманих результатів зумовлені потребами як самої теорії, так і потребами практики. Розв'язання задач поширення хвиль у системах зі стратифікованою структурою має застосування у океанології, біомеханіці, гідравліці, в інших галузях машино- та суднобудування. Ці дослідження не тільки дозволяють зі значною мірою точності моделювати реальні фізичні хвильові процеси, вони є необхідними для створення теоретичної бази для експериментів тощо.

Досліджується слабконелінійна задача про поширення хвиль на поверхні рідкого шару $\Omega_1 = \{(x,z) : |x| < \infty, -h_1 \le z < 0\}$ з густиною ρ_1 та верхнього рідкого шару $\Omega_2 = \{(x,z) : |x| < \infty, 0 \le z \le h_2\}$ з густиною ρ_2. Шари розділені поверхнею контакту $z = \eta(x,t)$, а верхній шар обмежений згори вільною поверхнею $z = \eta_0(x,t)$. При розв'язанні враховується сила поверхневого натягу на поверхні контакту та на вільній поверхні. Сила тяжіння направлена перпендикулярно поверхні розподілу у від'ємному *z*-напрямку, рідини вважаються нестисливими. Математична постановка задачі має вигляд: