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REGULARITIES OF MIXTURE FORMATION IN THE BURNERS OF THE STABILIZER TYPE WITH ONE-SIDED FUEL SUPPLY

The results of computer simulation of the processes of fuel and oxidizer mixing in stabilizer burner devices with one-sided fuel supply are presented. The effects of the influence of the length of flat flaps installed on the end surface of flame stabilizers on the distribution of methane concentration in their astern area are revealed. The analysis of concentration fields was carried out at varying the relative step of arrangement of the gas supply holes. It is shown that the required characteristics of the mixture of fuel and oxidant in the circulation zones behind the flame stabilizer for a given flap length can be provided at certain values of the indicated relative step. [dx.doi.org/10.29010/084.3]

Keywords: *stabilizer burner devices; one-sided fuel supply; CFD modeling; fuel and oxidizer mixture formation.*

Introduction

Stabilizer burners with the penetration of fuel into the stream of oxidizer are widely used in different fire-engineering facilities. The use of certain modifications of this type burners is largely determined by the level of excess air coefficient α, characteristic of this object. Thus, in burners oriented for operation in the range of α from 1.0 to 2.0 (which meets the operating conditions of the boiler units), there is a two-sided jet supply of fuel from the side surfaces of the flame stabilizers.

In burners designed to operate at higher values of α (gas turbine combustion chambers, industrial ovens, dryers, etc.), fuel can be supplied from only one of the side surfaces of the stabilizer. However, in this modification of burner devices, it is advisable to use flat flaps installed on the end surface of the flame stabilizers. These flaps should, on the one hand, contribute to the formation of stable zones of reverse currents in the astern areas of stabilizers, and on the other, to the formation of air flow, designed to reduce the level of temperatures in the central part of the zone of active combustion. Ensuring high environmental efficiency of this burner is associated with a marked decrease in temperature.

This article is devoted to research on stabilizer-type burners with one-sided fuel supply. In this case, the main attention in the work is paid to the processes of mixture formation of fuel and oxidant, which, as is well known, largely determine the main characteristics of combustion in the combustion space, such as the length of the torch, its shape, the completeness of fuel combustion, etc.

Problem statement and research methodology

Figure 1 illustrates the diagram of the module of the burner under consideration. This module consists of two flat flame stabilizers located in the channel at some distance from each other. In each of the stabilizers, the jet supply of fuel is carried out through a system of round holes on its side surface. The stabilizers are equipped with flat flaps, the functions of which are described above.

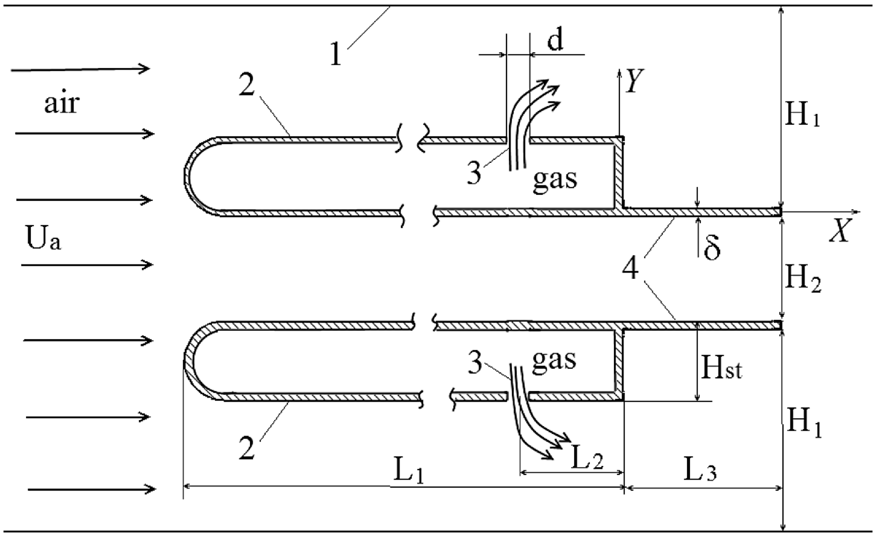

Fig. 1. Scheme of a microjet burner of stabilizer type with one-sided fuel supply: *1* – a flat channel; *2* – flame stabilizers; *3* – gas supply holes; *4* – flaps

The study of the regularities of the mixture formation of fuel and oxidant was carried out on the basis of CFD modeling. It should be noted that CFD modeling finds more and more widespread use for analyzing the working processes of different burner devices due to the improvement of the corresponding mathematical models, the possibility of obtaining local values of velocities, concentrations, temperatures, etc. [1-18].

The mathematical model of the process under study includes a system of partial differential equations, which in Cartesian coordinate system can be represented as follows:

$$\frac{\partial\left(\rho U_j U_i\right)}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial\left(\tau_{ij}\right)}{\partial x_j},\ i = 1,\ 2,\ 3, \qquad (1)$$

$$\frac{\partial\left(\rho U_j\right)}{\partial x_j} = 0, \qquad (2)$$

$$\frac{\partial\left(\rho_K U_j\right)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\nu}{Sc_K} + \frac{\nu_T}{Sc_T}\right)\frac{\partial \rho_K}{\partial x_j},\ K = 1,\ 2,\ \ldots\ N-1, \qquad (3)$$

where $\tau_{ij} = 2\left(\mu + \mu_T\right)S_{ij} - \frac{2}{3}\left[\left(\mu + \mu_T\right)\frac{\partial\, U_n}{\partial x_n} + \rho \cdot k\right]\delta_{ij}$,

$$S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right).$$

In the above equations, the summation is performed on a repeated index. Here: D_K, R_K – the diffusion coefficient and the velocity of formation of the K-th component; k is the kinetic energy of turbulent pulsations; N is the number of components of the mixture; P – static pressure; Sc_K is the Schmidt number of the K-th component; $Sc_K = \frac{\nu}{D_K}$; Sc_T is the turbulent Schmidt number; S_{ij} – components of the strain velocities tensor; U_j – components of the velocity vector in the direction x_j; C_K is the mass concentration of the K-th component; x_j – Card coordinate, $j = 1, 2, 3$; δ_{ij} – Kronecker symbol; μ, μ_T – molecular and turbulent dynamic viscosity; ν_T – turbulent kinematic viscosity; ρ – density of the medium; ρ_K – partial mass density of the K-th component, $\rho K = \rho \cdot C_K$; τ_{ij} – components of the stress tensor.

The numerical implementation of the solution of the problem under consideration was carried out using the FLUENT software. In this case, the DES (Detached Eddy Simulation) method was used, which is a hybrid approach, in which RANS (Reynolds Averaged Navier-Stokes – semi-empirical method based on the Reynolds averaged Navier-Stokes equations) and LES models (Large Eddy Simulation – a method of modeling large eddies) are switched in different areas of space [19, 20].

Particular attention was paid to the study of the regularities of the effect of the flap length on the characteristics of the mixture formation of fuel and oxidizer. The characteristics of the mixture formation were also analyzed for various values of the relative pitch S/d of the arrangement of the gas supply holes. The following computer simulation results meet the such initial data: S = 0.012 m; S/d = 4.0; S/d = 3.52; H_{st} = 0.015 m; H_1 = 0.04 m; H_2 = 0.02 m; L_1 = 0.2 m; L_2 = 0.02 m; δ = 0.0015 m, U_a = 10.0 m/s, α = 3.0; situations were considered that correspond to the absence of the flap L_3 = 0 and its presence with L_3 = 0.03 m; 0.045 m and 0.06 m.

Research results

Figure 2 shows the fields of mass concentration of methane C_{CH_4} in the longitudinal section of the burner under consideration in the absence of a flap (L_3 = 0) and its presence (L_3 = 0.03 m; L_3 = 0.06 m). Here zones I and II correspond to sub-regions with a high content of air and fuel, respectively. In the first zone, the mass concentration of methane is less than the lower concentration limit of ignition $C_{CH_4} < 0.028$, and in the second zone it exceeds the upper concentration limit $C_{CH_4} > 0.089$. In zone III, the value C_{CH_4} is in the concentration limits of ignition.

As can be seen from fig. 2, the patterns of the mixture of fuel and oxidant for the physical situations under consideration are qualitatively very similar in general. Namely, the areas of development of gas jets correspond to zones II with a high content of gas, near the channel wall, as well as in the interstabilization space, and sub-regions I with an increased air content occur somewhat downstream. In the astern areas of the stabilizer and further downstream there are the required concentration limits of the combustible mixture are provided.

As for the circulation flow zones behind the stabilizer, here the pattern of mixing with different values of L_3 is significantly different. Thus, with L_3 = 0, that is, in the absence of a flap, very low concentrations of methane occur in this zone, only slightly exceeding the lower concentration limit of ignition. At the same time, in the subregion adjacent to the lower part of the stabilizer end, the concentration of methane is less than the lower concentration limit of ignition. That is, in the absence of a flap, the conditions for flame stabilization in the astern area of the stabilizer are not sufficiently favorable.

In the presence of a flap with a length of L_3 = 0,03 m, the concentration of methane in the circulation flow zone behind the flame stabilizer also turns out to be rather low, although it corresponds to the concentration limits of ignition. With increasing flap length up to L_3 = 0.06 m, the value of C_{CH_4} in this zone

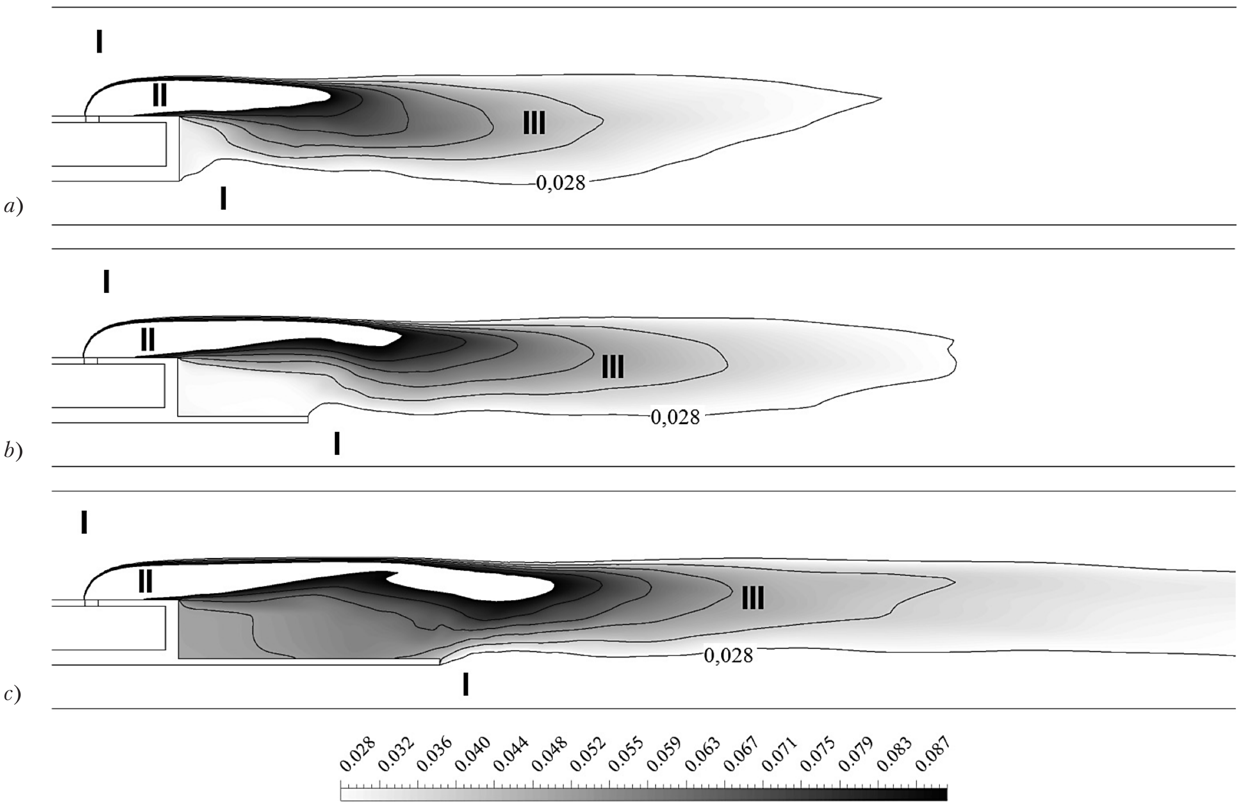

Fig. 2. Fields of mass concentration of methane in the longitudinal section of the stabilizer, passing through the axis of the gas supply holes, for S/d = 4.0, for different values of the flap length:
a) L_3 = 0, *b*) L_3 = 0.03 m, *c*) L_3 = 0.06 m. The contours are drawn in increments of 0.0103, starting at 0.028

increases significantly, reaching an average value of 0.06, which corresponds to the middle of the concentration interval of ignition.

Thus, in the conditions under consideration, an increase in the flap length contributes to the realization of the required mixture formation in the astern area of the stabilizer, which is a prerequisite for ensuring stable fuel combustion.

Figure 3 illustrates the change in the mass concentration of methane in two longitudinal sections of the burner device with different lengths of stabilizer. (Here, the coordinate X is measured from the end surface of the stabilizer, and Y – from its lower surface). As can be seen, in the sections under consideration, with the distance from the stabilizer end, the concentration of methane increases, reaches a maximum and then decreases. The differences in the values C_{CH_4} in the sections passing through the axis of the gas supply holes and in the middle between them are relatively small for both L_3 = 0.03 m and L_3 = 0.06 m. With regard to the effect of the flap length on the considered distribution of methane concentration, then it manifests itself most significantly near the end surface of the stabilizer and decreases with distance from it.

The results of the performed studies showed that the pattern of mixture formation of fuel and oxidizer in the circulation flow zone behind the flame stabilizer essenti-

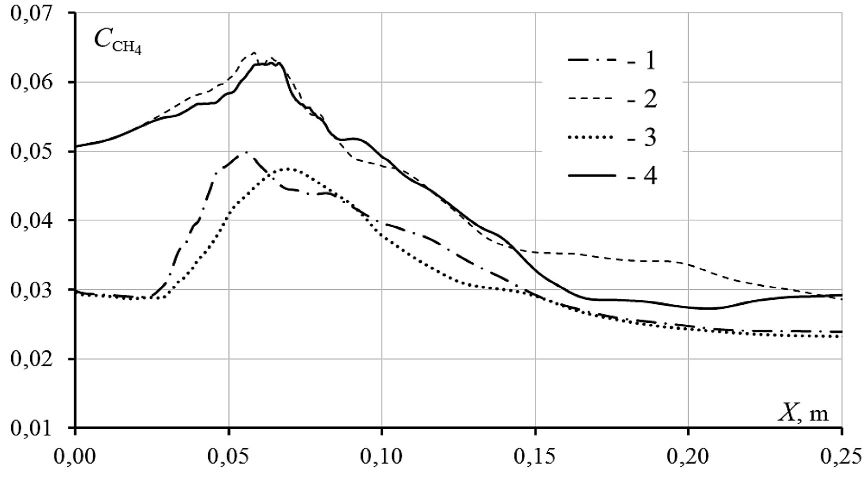

Fig. 3. Changes in the mass concentration of methane in the longitudinal sections passing through the axis of the gas supplying holes (lines *1*, *2*) and in the middle between them (lines *3*, *4*), for L_3 = 0.03 m (lines *1*, *3*) and L_3 = 0.06 m (lines *2*, *4*) with S/d = 4.0; Y = 0,0075 m

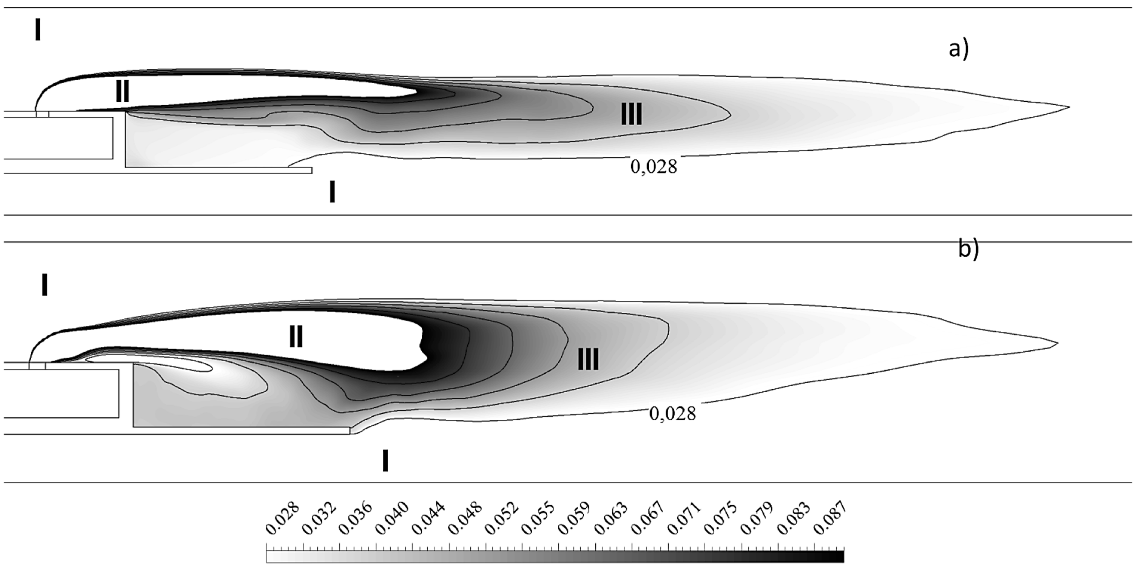

Fig. 4. Fields of mass concentration of methane in the longitudinal section of the stabilizer, passing through the axis of the gas supply holes, with different values of the ratio *S/d*: *a*) *S/d* = 4.0; *b*) *S/d* = 3.52. The contours are drawn in increments of 0.0103, starting at 0.028

ally depends on the relative pitch *S/d* of the location of the gas supply holes. A decrease in *S/d* leads to a decrease in the range of the fuel jets. Such pressure jets to the flame stabilizer causes an increase in the concentration of methane in the indicated circulation zone.

In Figure 4, 5, as an example, the data corresponding to *S/d* values equal to 4.0 and 3.52 with L_3 = 0.045 m are presented. According to the results of computer simulation at *S/d* = 4.0, the average value of methane concentration in the circulation flow zone behind the stabilizer is approximately 0.03, that is, it is located near the lower concentration limit of ignition. By reducing the *S/d* to 3.52, the indicated average value of the methane concentration rises to 0.05, approaching the middle of the concentration interval of ignition.

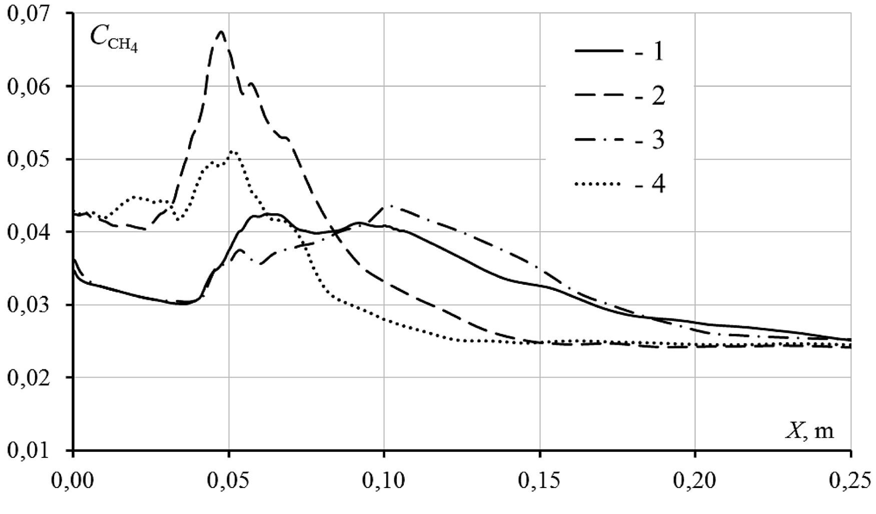

Fig. 5. Changes in the mass concentration of methane in longitudinal sections passing through the axis of the gas supply holes (lines *1*, *2*) and middle between them (lines *3*, *4*), for *S/d* = 4.0 (lines *1*, *3*) and *S/d* = 3.52 (lines *2*, *4*) with L_3 = 0.045 m; *Y* = 0,0075 m

Thus, the required average value of methane concentration in the circulation flow zone behind the flame stabilizer at a given flap length L_3 can be achieved by choosing the appropriate relative distance *S/d* between the gas supply holes.

Conclusions

1. On the basis of CFD modeling, the main features of the mixture formation of fuel and oxidizer in stabilizer burner devices with one-sided jet supply of fuel gas to the oxidizer stream are investigated.

2. The analysis of the effect of the length of flat flaps installed on the end surface of flame stabilizers on the patterns of fuel and oxidizer mixing was performed. It is shown, in particular, that in the considered range of variation of parameters, an increase in this length causes an increase in the average methane concentration in the circulation flow zone behind the stabilizer responsible for the stability of the combustion process.

3. Data about the dependence of the characteristics of the mixture formation of the fuel and oxidizer on the relative distance between the gas supply holes were obtained. It has been established that with a fixed flap length, the necessary parameters of the mixture in the circulation flow zone behind the flame stabilizer can be provided by selecting the appropriate value of the indicated distance.

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ЗАКОНОМЕРНОСТИ СМЕСЕОБРАЗОВАНИЯ В ГОРЕЛКАХ СТАБИЛИЗАТОРНОГО ТИПА С ОДНОСТОРОННЕЙ ПОДАЧЕЙ ТОПЛИВА

Представлены результаты компьютерного моделирования процессов смесеобразования топлива и окислителя в стабилизаторных горелочных устройствах с односторонней подачей топлива. Выявлены эффекты влияния длины плоских закрылков, установленных на торцевой поверхности стабилизаторов пламени, на распределение концентрации метана в их закормовой области. Выполнен анализ концентрационных полей при варьировании величины относительного шага расположения газоподающих отверстий. Показано, что требуемые характеристики смеси топлива и окислителя в циркуляционных зонах за стабилизатором пламени для заданной длины закрылка могут быть обеспечены при определенных значениях указанного относительного шага. [dx.doi.org/10.29010/084.3]

Ключевые слова: *стабилизаторные горелочные устройства; односторонняя подача топлива; CFD моделирование; смесеобразование топлива и окислителя.*

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