Технічні науки

UDC 621.1.016:621.184

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REGULARITIES OF NON-ISOTHERMAL FLOW IN MICRO-JET BURNERS WITH MULTI- ROW FUEL SUPPLY

Summary. *The paper presents the data of CFD modeling of the flow in micro-jet burners with a multi-row fuel supply system. The results of studies of the dependence of the flow characteristics on the distance of the gas supply holes to the breakaway edge of the flame stabilizers are given.*

Key words: *micro-jet burners, computer modeling, flow structure, natural gas combustion.*

Increasing the efficiency of burner devices requires conducting in-depth studies of operating processes [1-15]. The latter are studied based on the study of so-called elementary processes, which together model the process of fuel preparation and combustion as a whole. The efficiency of fuel combustion depends significantly on such an elementary process as the aerodynamics of the burner device. Its study, as a rule, occurs in two stages. The first stage is preliminary and meets the conditions of isothermal flow [4-23]. The flow structure under conditions of reacting flows is considered at the second stage of the study [24-28].

The aim of the work is to establish, using CFD modeling data, the patterns of flow of reacting streams in a micro-jet burner device with a three-row fuel supply system, designed for operation at different values of the excess air coefficient.

The situation corresponding to the presence of one fuel module in the channel is subject to study. The processes of non-isothermal flow in a burner oriented to operation at variable values of the excess air coefficient, $1.1 \le \alpha \le 1.5$, are considered.

The diagram of the burner module under study is shown in Fig. 1. Flame stabilizer 2 is located in channel 1. Fuel gas is supplied through one of the three sections I, II, III at an excess air coefficient of 1.1; 1.3; 1.5, respectively.

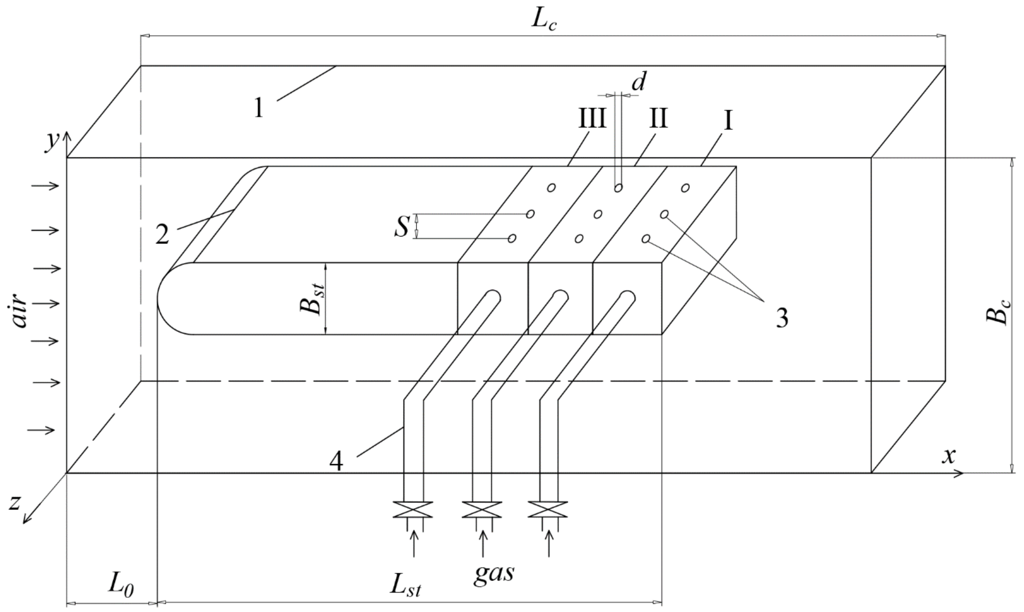

Fig. 1. Schematic diagram of the stabilizer-type micro-jet burner module with a three-row fuel supply system: 1 - flat channel; 2 - flame stabilizer; 3 - gas supply holes; 4 - gas supply pipes; I, II, III - fuel supply sections with different values of the relative step of the gas supply holes, corresponding to the values of the excess air coefficient of 1.1; 1.3; 1.5

The mathematical model of the process under study looks like this.

Equation of motion

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

Continuity equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho U_j)}{\partial x_j}=0\cdot \quad (2)$$

The energy equation for reacting turbulent flows, presented in the form of an enthalpy transfer equation *h*

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x_j}(\rho U_j h)=\frac{\partial}{\partial x_j}\left[\left(\frac{\mu}{Pr}+\frac{\mu_T}{Pr_T}\right)\frac{\partial h}{\partial x_j}\right]+q_h \quad (3)$$

Equation of conservation of mass of components of a reacting mixture

$$\frac{\partial \rho_K}{\partial t}+\frac{\partial(\rho_K U_j)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\frac{\nu}{Sc_K}+\frac{\nu_T}{Sc_T}\right)\frac{\partial \rho_K}{\partial x_j}+R_K, \qquad K=1,2,\ldots N\text{-}1, \quad (4)$$

where ρ is the density of the medium; *t* is time; x_j is the Cartesian coordinate, j = 1,2,3; U_j are the components of the velocity vector in the x_j direction; *P* is the static pressure; $\tau_{i,j}$ are the components of the stress tensor, $\tau_{ij}=2(\mu+\mu_T)S_{ij}-\frac{2}{3}\left[(\mu+\mu_T)\frac{\partial U_n}{\partial x_n}+\rho\cdot k\right]\delta_{ij}$, *k* – kinetic energy of turbulent pulsations, μ, μ_T – molecular and turbulent dynamic viscosity, $\delta_{i,j}$ – the Kronecker symbol; $S_{i,j}$ – components of the strain rate tensor, $S_{ij}=\frac{1}{2}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)$; Pr – Prandtl number, $\mathrm{Pr}=\frac{\nu}{a}$, *a*, ν – thermal conductivity and kinematic viscosity, respectively; Pr_T – turbulent Prandtl number; q_h – a term that takes into account the heat of chemical reactions and heat transfer by radiation; ρ_K – partial mass density of the Kth component, $\rho_K=\rho\cdot w_K$, w_K – mass concentration of the Kth component; *N* – number of components of the mixture; Sc_K – Schmidt number of the *K*th component, $Sc_K=\frac{\nu}{D_K}$, D_K, R_K – diffusion coefficient and rate of formation of the

*K*th component; ν_T – turbulent kinematic viscosity; Sc_T – turbulent Schmidt number.

The limiting conditions for the system of differential equations (1) – (4) were determined as follows. Constant values of the corresponding quantities (velocities, concentrations, temperatures) were set in the inlet section. Soft boundary conditions were adopted in the section at the outlet of the burner channel. At the rigid boundaries of the burner, no-slip conditions were set for the velocities and the equality to zero of the first derivatives along the normal to these boundaries from the concentrations of the mixture components. The thermal conditions on the lateral surface of the channel were the conditions of water cooling of its walls. The solution of this system of equations was carried out based on the DES approach.

The typical results of the performed studies are shown in Fig. 2-3. The presented data correspond to the following initial parameters: B_{st}=0.03 m; B_c=0.075 m; L_c=1.3 m; L_0=0.1 m; L_{st}=0.2 m; the coefficient of blocking of the flow section of the channel k_f =0.4 (k_f=B_{st}/B_c). The value of the total excess air coefficient α_Σ, the distance L_1 between the stabilizer breakaway edge and the corresponding gas supply holes, the relative step of the gas supply holes *S*/*d* and the air velocity at the channel inlet U^a_{in} for feeding fuel to different sections are given in Table 1. Turbulence intensity *Tu* in the inlet section of the channel *Tu*=3%. Natural gas was used as fuel, and air as an oxidizer. The operating conditions of the burner device correspond to its constant heat output.

Table 1

Design parameters of the three-row jet fuel supply system and the value of the velocity at the channel inlet

N_R	α_Σ	L_1, 10^{-3}·м	*d*, 10^{-3}·м	*S*/*d*	U^a_{in}, м/s
1	1,1	40	3,8	4,21	5,00
2	1,3	55	3,5	4,57	5,91

3	1,5	70	3,3	4,85	6,82

The results of the studies show that the structure of the non-isothermal flow when feeding fuel gas into different rows of gas-feeding holes has certain common patterns. The latter concern the development of fuel jets in the oxidizer carryover flow, the formation of recirculation zones in the stabilizer feed area, etc. However, the flow characteristics may differ significantly when feeding fuel gas through the first, second and third rows of gas-feeding holes. Thus, according to computer modeling data, with an increase in the fuel feed row number N_R, the length of the recirculation zone in the stabilizer feed area increases from 88 mm to 98 mm and then to 107 mm, respectively. The maximum absolute value of the velocity in this zone also increases and is 3.9 m/s; 4.6 m/s and 5.1 m/s when feeding fuel into the first, second and third sections.

As the data in Fig. 2 show, differences in the pattern of the velocity fields $U_x=f(x)$ are also noticeable under the conditions of fuel supply to different sections. (In the figure, the dark zones along the flame stabilizer correspond to negative and low values of the velocity, and the darkened zones at the outlet section of the channel correspond to its high values). Namely, the higher the number N_R of the fuel gas supply section, the higher the flow velocity level in general. At the same time, the width of the region of increased velocities at the outlet of the channel increases with an increase in the section number.

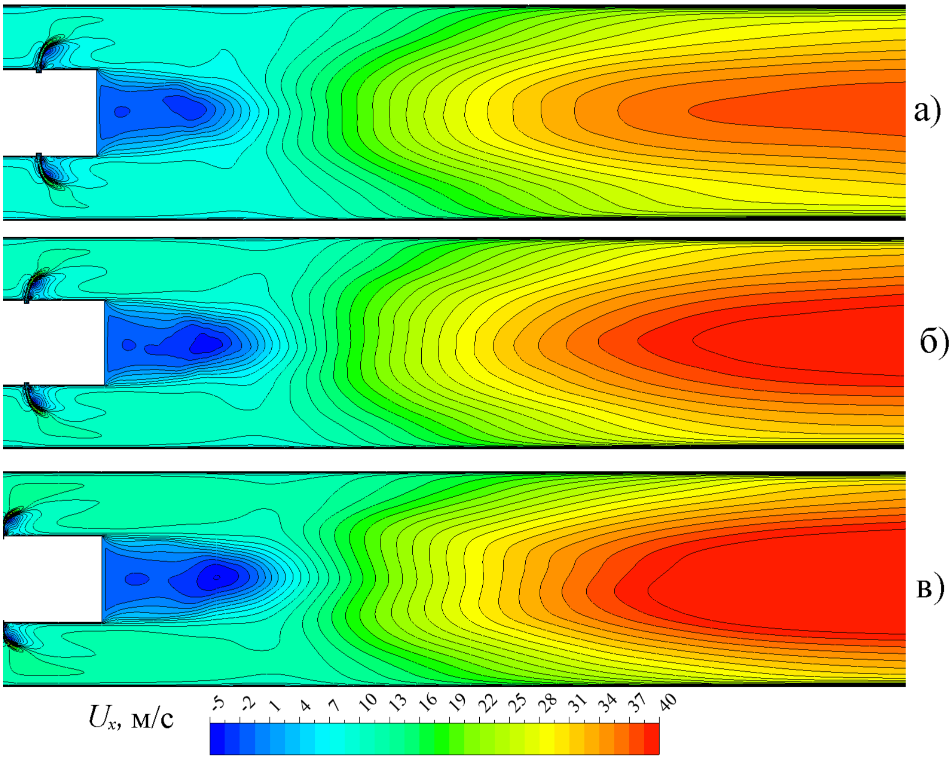

Fig. 2. The velocity field U_x in the longitudinal section of the flame stabilizer passing through the axis of the gas supply holes, when fuel is supplied to the first (a), second (b) and third (c) sections

Figure 3 shows the fields of mean square velocity pulsations U_{mag}' when fuel gas is supplied to different rows of gas supply holes.

As the presented data show, the highest overall level of velocity pulsations U_{mag}' is observed when fuel gas is supplied to the second fuel supply section, lower - to the first section and the lowest - to the third section. That is, the dependence of the specified pulsation level on the fuel supply section number is non-monotonic. This is explained by the action of a number of competing factors. In particular, an increase in the oxidizer flow rate with an increase in the excess air coefficient and, accordingly, the row number, on the one hand, can contribute to an increase in the level of velocity pulsations, and on the other hand, to its decrease, taking into account the decrease in combustion intensity.

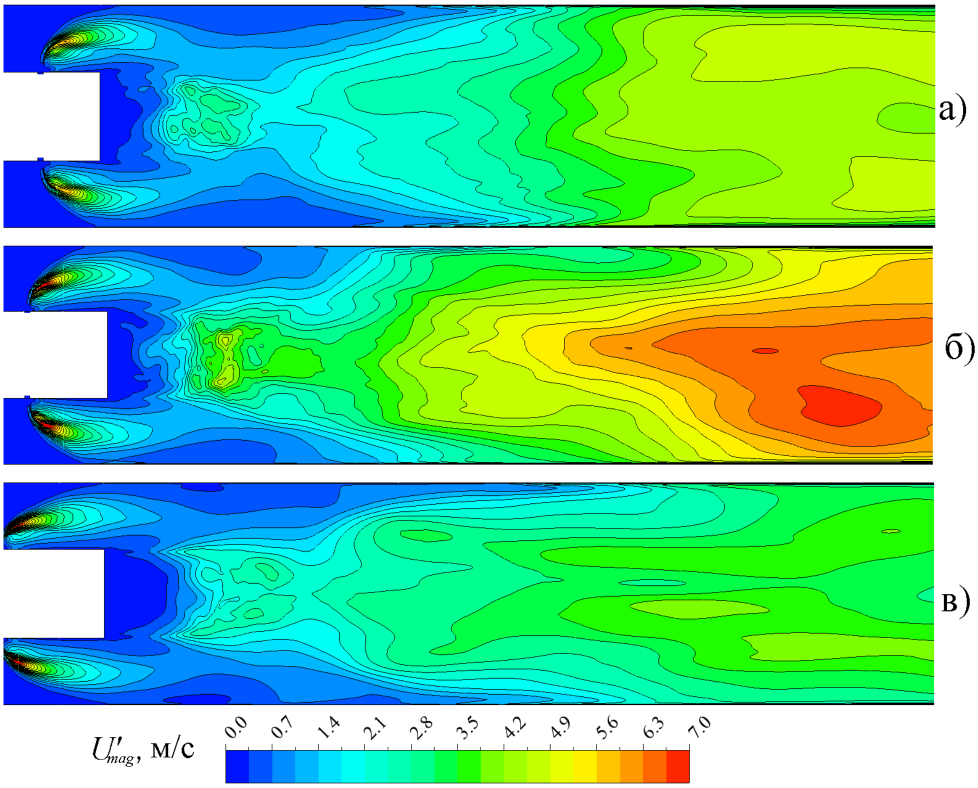

Fig. 3. Field of root-mean-square velocity pulsations $U_{mag}{}'$ in the longitudinal section of the flame stabilizer passing through the axis of the gas supply holes, when fuel is supplied to the first (a), second (b) and third (c) sections

Conclusions. Data were obtained on the patterns of flow of reacting streams in micro-jet burners of the stabilizer type, designed for operation at variable values of the excess air coefficient (1.1...1.5). A comparative analysis of the flow characteristics when feeding fuel gas into different rows of gas supply holes was performed. It was shown that these characteristics can significantly depend on the fuel supply row number. Namely, with its increase: the recirculation zone parameters change along the flame stabilizer – its length and maximum absolute values of velocity in this zone increase noticeably; the flow velocity levels increase in general; the area of increased velocities near the outlet section of the channel covers an ever larger part of the channel cross-section; a non-monotonic nature of the change in the overall level of velocity pulsations is observed. The highest level corresponds to fuel supply to the second section, the lowest – to the first, and the lowest – to the third. An interpretation of this effect is given based on certain competing factors.

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