THE INFLUENCE OF THE BURNER CHANNELS FLOW SECTION BLOCKAGE FACTOR DUE TO ECHELONED STABILIZERS ON THE FLOW CHARACTERISTICS

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The investigations results of the laws of fuel and oxidant flow at varying the value of the blockage coefficient of the channel crossing of microjet burners by echeloned stabilizers are submitted. The data of mathematical modeling to establish of the effects of the impact of this the blockage coefficient on development features of fuel jet introduced in the razing oxidant stream, the characteristics of the circulation flow in the near wake of stabilizers and so on are presented.

Factor blockage of the channel crossing, microjet burner, flame stabilizers ladder location.

The increasing of flow section blockage in the burners channels used, as is well known, as a means of the flame length reducing. In this case, it is increased the amount of flame stabilizers in the grid so that when a total natural gas flow rate is constant there is decreasing its flow rate per one stabilizer. This leads to the required reduction of the flame length when burning. However, at a sufficiently high degree of flow section blockage under conditions when the ends of the stabilizers are arranged in plane, a spontaneous flow symmetry breakage arises. The latter can be eliminated by means of echeloned arrangement of flame stabilizers in the grid.

Thus, the provision a relatively small flame length while retention the flow stability is possible only under condition when, along with a flow section blockage degree increasing the echeloned stabilizer grid is used.

In the last period of time the study of various aspects of the microflame burners operation with echeloned flame stabilizer grids an increasing attention is paid (see. Eg. [1-4]). However, a number of issues related to these processes for various design of considered burners, remains unexplored.

The purpose of the research – identification the main features of fuel and oxidizer flow structure in microflame burner devices with stair shaped echeloned flame stabilizer grids by varying the degree of flow section blockage in these devices.

The materials and methodology of the research. The subject of research is a structure of natural gas and air flow in the microflame burners with stair shaped flame stabilizers arrangement. The mathematical formulation of the transfer problem can be represented as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho U_j)}{\partial x_j} = 0, \tag{1}$$

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

$$\frac{\partial \rho_\kappa}{\partial t} + \frac{\partial(\rho_\kappa U_j)}{\partial x_j} = \frac{\partial}{\partial x_j}\left(D_\kappa \frac{\partial \rho_\kappa}{\partial x_j}\right), \tag{3}$$

$\kappa = 1,2,\ldots N\text{-}1$,

where x_j – Cartesian coordinate, m, j = 1, 2, 3; U_j – velocity vector component in the direction of the axis x_j, m/s; P – static pressure, Pa; $\tau_{i,j}$ – components of the stress tensor, N/m^2; ρ– density, kg/m^3; ρ_k – partial mass density of k-component, kg/m^3, $\rho_\kappa = \rho \cdot W_\kappa$; W_κ – mass concentration; D_k – diffusion factor of k-component, m^2/s.

Numerical implementation of the task was carried out on the basis of DES (Detached Eddy Simulation). This method, as known, has been proposed as an alternative to RANS (Reynolds Averaged Navier-Stokes) and LES (Large Eddy Simulation) methods in the calculation of near wall flows with extensive detached zones for which RANS models are not able to provide acceptable accuracy and LES requires excessively large computational resources. At the same time it was taken into account the fact that the lion's share of the LES computational cost associated with calculation of the near-wall attached boundary layers, which contain energy transportation vortices of small size, and that a computation exactly of such flows by using RANS is sufficiently reliable and economical. This naturally led the authors of DES to idea of creating a combined RANS-LES model which would unite the best qualities of the two methods, namely, reliability and computational efficiency of RANS for the attached boundary layers with high accuracy and reasonable computational cost of LES at a distance from the walls [5, 6, 7].

The principal difference DES from LES is that within DES "accurately" means that not all of energy-vortices are calculated, but only "detached" vortices in the detach zone, and the vortices which are contained in the area of attached boundary layers, described by the usual semi-empirical RANS models. The another important feature of DES is that within the framework of this approach in RANS and in LES regions is used the same "base" turbulence model, which works as a RANS model within the wall boundary layer and as its subgrid (Sub-Grid Scale or SGS) analogue at a distance from the solid walls.

The realization of the above-described DES idea is based on the fact that RANS and LES equations have, as was mentioned, the overall form. In addition, it is assumed that the RANS model, based on which a DES model is being built, can be transformed into a subgrid model for LES by replacing the linear scale of turbulence l_{RANS}, explicitly or implicitly included in all RANS models, for sub-grid scale $l = c\Delta$. Then, by introducing a hybrid linear scale as $l_{DES} = \min(l_{RANS}, c_{DES}\Delta)$, where c_{DES} – additional constant of the model, similar to Smagorinsky constant, we obtain DES model, which, depending on the ratio of the RANS and LES linear scales, works either as basic RANS model or as its subgrid version. As a result, in the flow fields, where the mesh is too rough and unsuitable for resolving the turbulence structures, that is when $c_{DES}\Delta > l_{RANS}$, DES operates as RANS, and in the areas where the mesh is sufficiently fine, that is when $c_{DES}\Delta < l_{RANS}$, – as sub-grid model for LES. An important feature of DES is also the fact that as the characteristic dimension of the "filter" it uses a maximum of three grid steps at the flow point under consideration: $\Delta = \max(\Delta x, \Delta y, \Delta z)$. [6, 7]

The following are the results of mathematical modeling in the framework of study the regularities of the channel flow section blockage factor influence k_f on the flow characteristics in the stair-shaped echeloned grid of flame stabilizers ($k_f = B_{ст} / H$, where $B_{ст}$ – stabilizer width, H – stabilizers arrangement pitch). In this situation, under consideration are two cases corresponding to location two or three flame stabilizers in the burner channel with the width $B_к$ = 200 mm, that is corresponds to the values of k_f = 0,3 and 0,45 (see. Fig. 1). The total air consumption

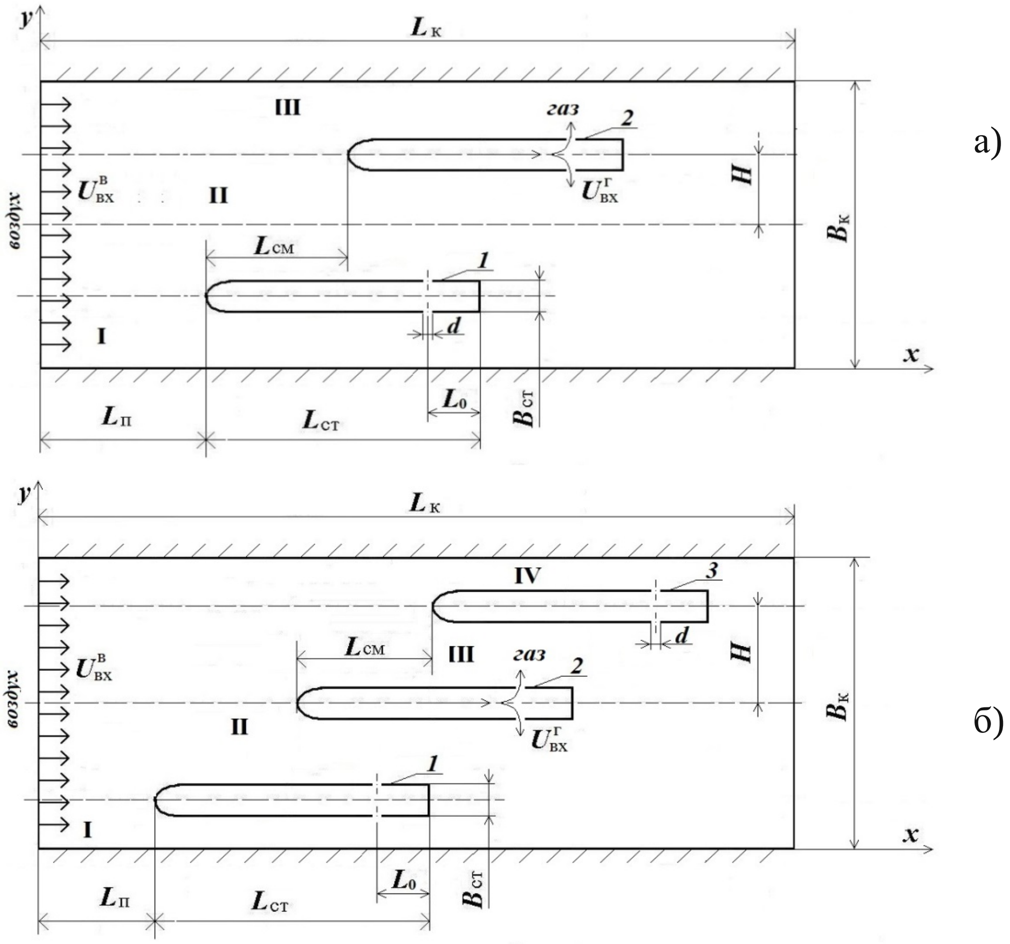

Fig. 1. By the problem statement for the stair-shaped echeloned stabilizer grids for different values of flow section blockage factor of the channel: k_f = 0,3 (a) and 0.45 (b): 1, 2 and 3 - the first, second and third flame stabilizers; I, II, III, IV – channels of stabilizer grid

through the burner device was 0.165 m^3/s (600 m^3/h), and the natural gas – 0,0139 m^3/s (50 m^3/h). Other input data for the mathematical modeling were the same for the two situations: $L_п$ = 0.2 m; $L_{ст}$ = 0.215 m; $L_к$ = 1.5 m; H = 0,075 m; B_k = 0,225 m; $B_{ст}$ = 0.03 m; $L_{см}$ = 0.06 m; L_0 = 0,02 m; d = 0,0045 m; S/d = 3,55, where S – the spacing of natural gas supplying openings.

The results of the research. At Fig. 2, 3 and in Tables 1 and 2 are shown the typical results of the research.

Fig. 2 illustrates a field of longitudinal component of the velocity vector U_x for the grid, consisted of two (k_f = 0,3) and three (k_f = 0,45) flame stabilizers. Table 1 shows the average speed U_x in the grid channels. As can be seen from obtained data, the greater k_f magnitude the more asymmetrical flow patterns appear in the stabilizer grid channels. So when k_f = 0,3 the difference of average velocities in the near-wall channels is 9%, and when k_f = 0,45 – reaches up to 22.6%.

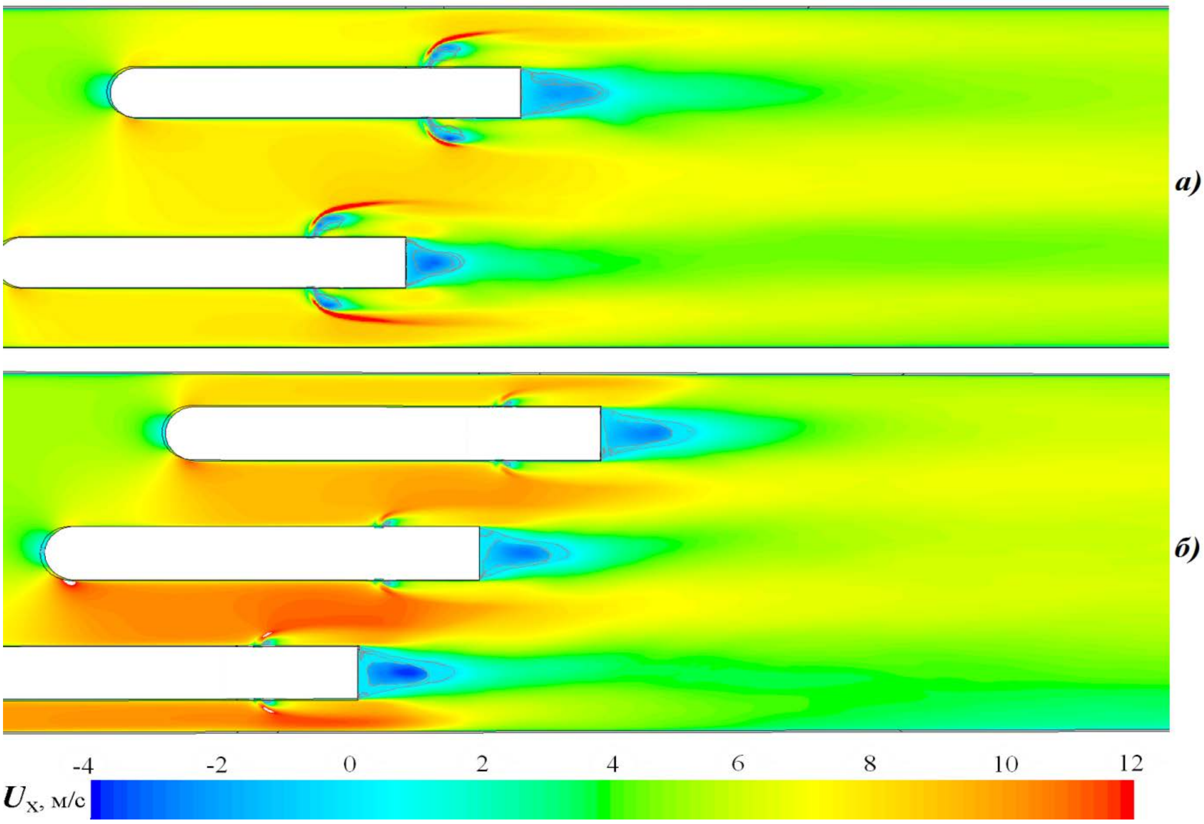

Fig. 2. The fields of longitudinal velocity component U_x at different values of flow section blockage factor of the channel: k_f = 0,3 (a) and k_f = 0,45 (b)

Table 1. The average values of the velocity U_x (m/s) in channels of the grid

k_f	The channel number			
	I	II	III	IV
0,3	7,39	7,49	6,78	-
0,45	9,60	10,11	9,02	7,82

As for the nature of the natural gas jets progress which are being introduced in entraining air flow, according to the data presented at Fig. 2, the depth of its penetration is much lower in case when k_f = 0,45. This is obviously due to, on the one hand, a lower gas consumption per one stabilizer, and the other – higher air velocities in the grid channels.

Table. 2 shows the size of the zones with reverse currents and maximum values of velocities in these areas when k_f = 0,3 and k_f = 0,45.

Table 2. The length of reverse current zones $L_{\text{от}}$ and maximum modulo of velocity $U_{\max}$ in these areas behind *i*-th flame stabilizer for different values of k_f

k_f	0,3		0,45		
i	1	2	1	2	3
$L_{\text{от}}$, 10^{-3}м	30,8	46,1	47,5	44,5	46,5
$U_{\max}$, м/с	3,1	2,05	3,76	2,86	2,67

Fig. 3 illustrates the fields of root-mean-square (RMS) value of the velocity pulsations $\overline{U'}$ for different k_f values. As can be seen, the values of velocity pulsations $\overline{U'}$ in stabilizer astern areas are increased significantly with increasing the flow cross section blockage factor of the channel k_f. Thus when k_f = 0,45 the pulsations $\overline{U'}$ reach maximum values of 6.2 m/s, and when k_f = 0,3 – do not exceed 4,3 m/s. Attention is drawn to the fact that for k_f = 0,45 the values of $\overline{U'}$ are significantly higher in mentioned astern areas compared with the areas of jet development, and for k_f = 0,3 the pulsations $\overline{U'}$ are similar by size in these areas.

The data obtained by the mathematical modeling of pressure fields at different values k_f authenticate that for k_f = 0,3 the lowest pressure values are observed in areas of the jets development. When k_f = 0,45 the zones of low pressure occur in these areas of jets development, and in astern zones of stabilizers. As for the pressure level in the stabilizer grid channels, they are generally significantly higher by smaller value of flow section blockage factor of the burner channel.

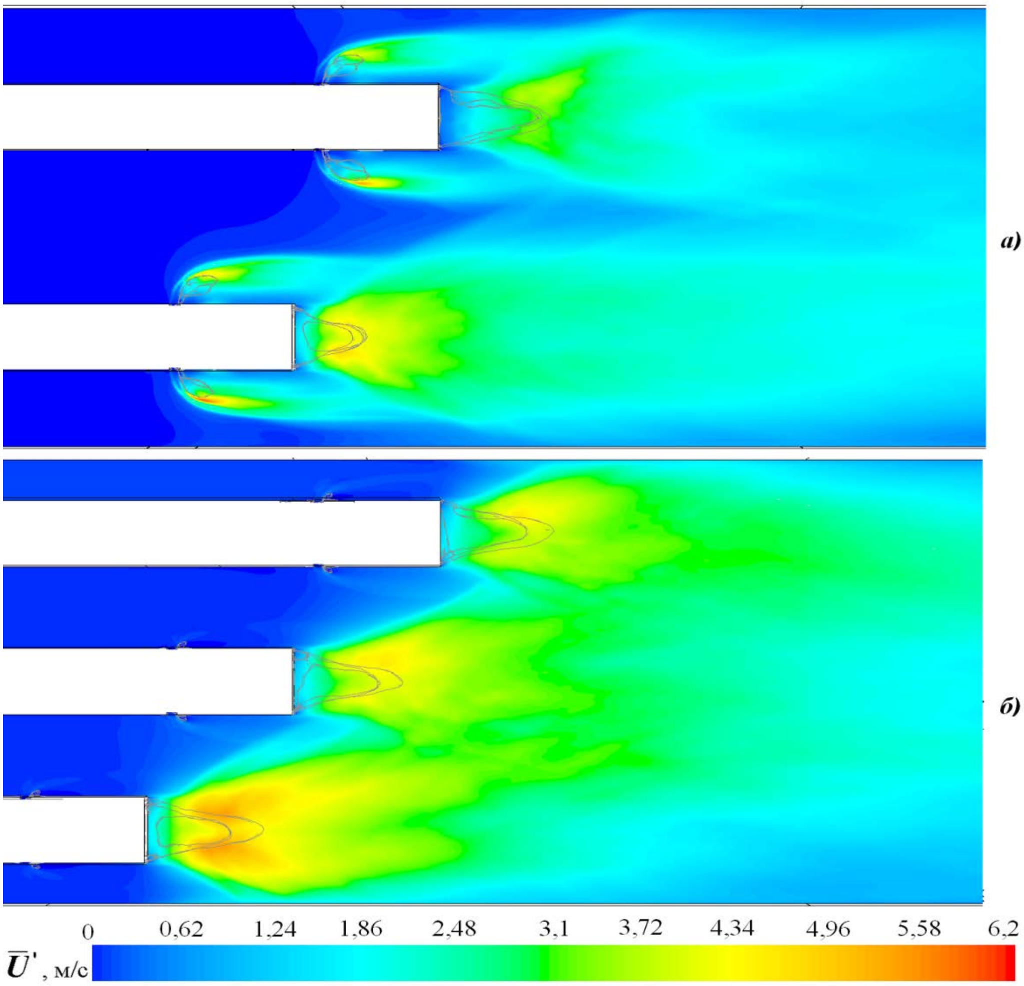

Figure 3. Field of RMS velocity pulsations $\overline{U'}$ at different values of flow section blockage factor of the channel: k_f = 0,3 (a) and k_f = 0,45 (b)

It is obviously that the increasing of the burner flow section blockage should lead to pressure loss increase in the burner device. According to the results of the research in examine situation when k_f = 0,3 these losses reach 15,6 Pa, and when k_f = 0,45 – reach 32,9 Pa.

Conclusions.

The regularities of the influence on the fuel and oxidant flow structure by burner flow section blockage degree by flame stabilizers of microflame burner with the stair-shaped arrangement of flame stabilizers are established. An increase of blockage factor value stipulates the increase of asymmetric flow in the stabilizer grids, the reducing of the fuel jets penetration depth to the oxidant stream, the marked increase of the velocity pulsations in stabilizers astern areas, as well as a significant increase of pressure loss in the burner device are shown.

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