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SPECIFICS OF FLOW AND MIXING IN MICRO-FLAME CYLINDRICAL BURNER DEVICES DIFFERENT CAPACITIES

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The results of CFD simulation of the complex research of aerodynamics and mixing are given for type series of micro-flame cylindrical burners with power from 20 to 200 kW. The developed recommendations for choosing the rational design parameters considered burners are offered.

CFD modeling, cylindrical burners, aerodynamics, fuel and oxidizer mixing

Burners relatively low capacity are widely used in AIC power equipment for various purposes. Their use is very effective for fire engineering objects not only of relatively small, but different heat productivity under conditions where high demands are placed on the uniformity of the heat in the firing space.

For selected situations is advisable to use micro-flame burners with cylindrical flame stabilizers. Their higher efficiency compared with traditional burner devices which use flat stabilizers, caused mainly by the lack of various kinds of losses associated with end effects. Besides practical importance is the fact that the cylindrical burners due to the configuration features is relatively easy to integrate into the design of power equipment.

Analysis of the state of research concerning the creation of high-efficient micro-flame cylindrical design, suggests that the existing individual papers devoted to this subject, do not exhaust the needs of the energy practice (see, for example, [1-3]). This necessitates the further research development of various elements of micro-flame cylindrical burner workflow.

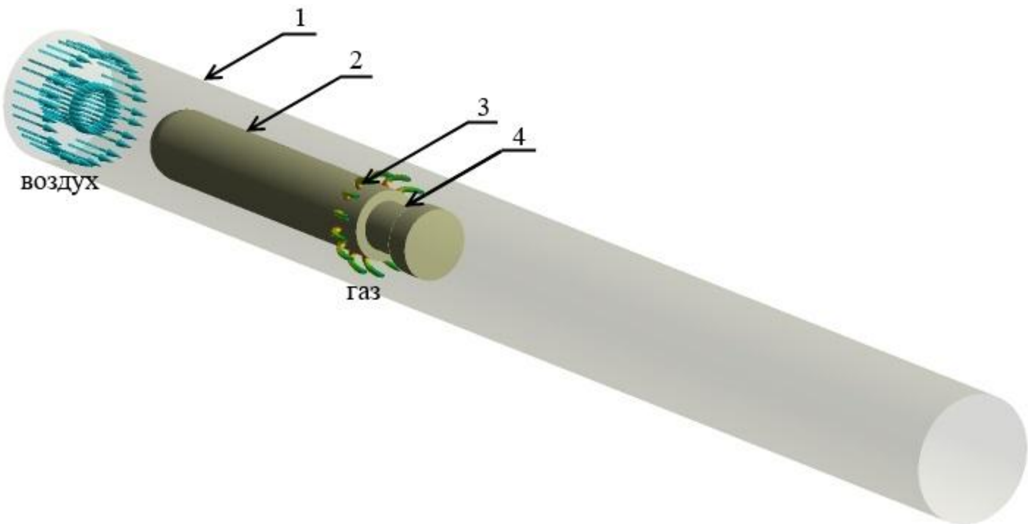
The purpose of the work. Establishment of the flow and mixing behavior in the micro-flame cylindrical burner devices of different capacities and choice of their rational design parameters.

The material and methods research. The burner unit is considered which is a circular channel with cylindrical stabilizer with a rounded front and a blunt trailing edge (Fig. 1). The stabilizer is provided with a system of circular holes through which a transverse flow of gas penetrates into the air stream. The holes are located in front of the displaced downstream ring-shaped rectangular cavity.

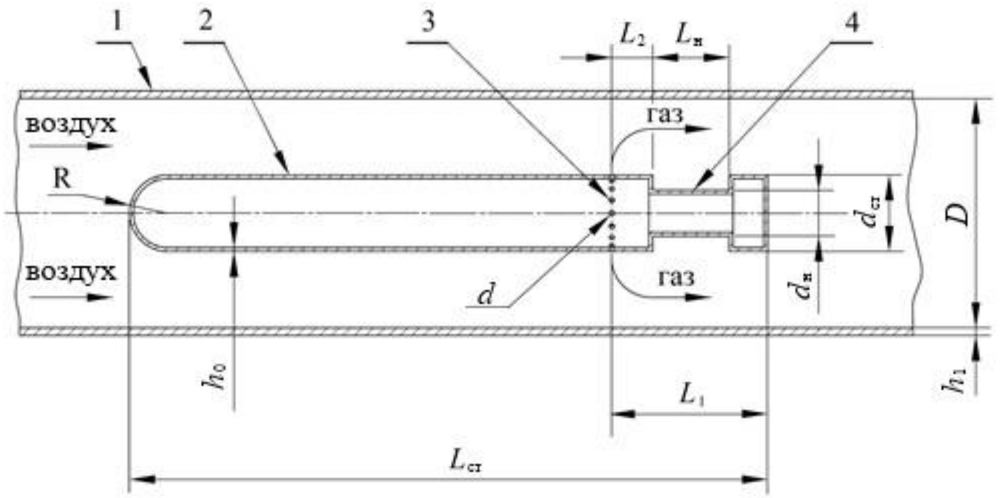
The mathematical model of the investigated processes of flow and mixing in micro-flame cylindrical burner device can be represented in the form:

$$\nabla \cdot \left(\rho \vec{U}\vec{U}\right) = -\nabla p + \nabla \cdot \bar{\bar{\tau}}, \quad (1)$$

$$\nabla \cdot \left(\rho \vec{U}\right) = 0, \quad (2)$$



a)



b)

Fig. 1. Scheme (a) and longitudinal sectional view (b) of a burner device with a cylindrical flame stabilizer: 1 - circular channel; 2 - cylindrical flame stabilizer; 3 - gas supply holes; 4 – ring-shaped cavity

$$\nabla \cdot \left(\rho \vec{U} Y_i \right) = \nabla \cdot \left(\left(\frac{\mu}{Sc_i} + \frac{\mu_t}{Sc_t} \right) \nabla Y_i \right), \qquad i = 1,2,\ldots,N\text{-}1, \tag{3}$$

$$\rho = \frac{P}{RT \sum_i \frac{Y_i}{M_i}}, \tag{4}$$

where $\vec{U}$ – the velocity vector; p – the pressure; $\bar{\bar{\tau}}$ – the stress tensor; ρ – the density; μ, $\mu_т$ – coefficients of molecular and turbulent dynamic viscosity; Y_i – the mass fraction of the i-th component of the mixture; M_i, D_i, Sc_i – the molecular weight, the diffusion coefficient and the Schmidt number of the i-th component, $Sc_i = \mu/\rho D_i$; $Sc_т$ – the turbulent Schmidt number; N – number of components of the mixture; T – the absolute temperature; R – the universal gas constant.

The closure of the equations system is based on the use of RNG k-ε turbulence model.

In view of the regularity of the gas supply holes location a characteristic element of the burner is simulated, which is an angular fragment ($0 < \varphi < \varphi_1$). Here φ_1 corresponds to half the angular spacing between the holes, and includes half of them. In the inlet section of the selected element is set to air speed, the degree of turbulence and temperature. In the gas supply holes cross section located in the stabilizer sidewall are given gas velocity, the degree of turbulence and the temperature.

On the other wall surfaces of the stabilizer and the side surfaces of the channel the conditions of adhesion and impermeability are accepted. On the surfaces of the selected element $\varphi = 0$ and $\varphi = \varphi_1$ symmetry conditions are specified, in the outlet section boundary conditions corresponding to the zero derivatives with respect to the normal to the boundary of the dependent variable are set up.

The numerical implementation of the solution of the problem was carried out using a software package FLUENT.

The research results. The results of numerical studies of flow and mixing of fuel and oxidizer to type series micro-flame cylindrical burners are presented below. This series includes five burners, respectively, 20, 65, 110, 155 and 200 kW.

Fig. 2-5 for the type series illustrate the results of computer simulation of the following values of the input parameters. Natural gas flow rate is 2; 6,5; 11; 15,5 and 20 m^3/h for specified burners capacity; excess air ratio α = 1,1; stabilizer length L_{st} = 0,25 m; dimensions of the rectangular ring-shaped cavity are 0,03x0,006 m; the air flow turbulence intensity in channel inlet I_a = 3%; natural gas flow in the gas supply hole cross-section has turbulence intensity that equals I_g = 3%; absolute temperature of the gas and air is 300 K. Other initial data are different for various burner capacity.

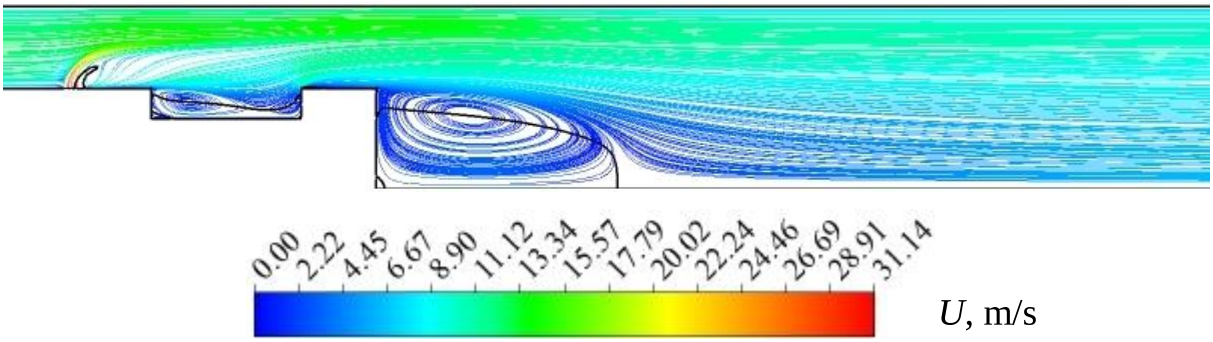


Fig. 2. Stream lines in the longitudinal section of the cylindrical stabilizer of the burner through the center of the gas supply hole

The results of these studies indicate that the basic behavior of the flow of fuel and oxidizer are stored at different power burner. The stream lines to the burner 110 kW in the section φ = 0, passing through the gas supply hole center are presented in Fig. 2. As can be seen, under these conditions the penetrating of gas jets in the oxidant stream and vortex capture in the cavity are observed. In the stabilizer astern area a recirculation zone is formed and further downstream there is an alignment of the velocity profile and the formation of a stabilized flow in the channel.

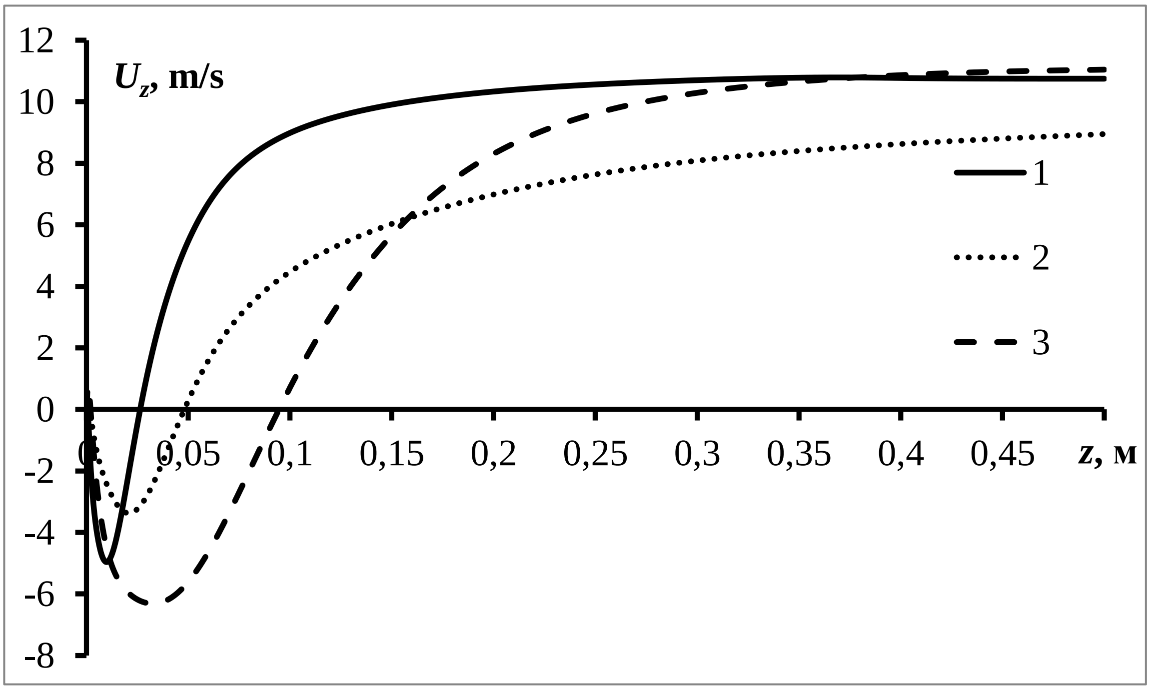


Fig. 3. The distribution of the axial velocity component U_z along the turbulent wake behind a cylindrical stabilizer for burners of different power N_b: 1 - N_b = 20 kW; 2 - N_b = 110 kW; 3 - N_b = 200 kW

Flow pattern in the burner of different capacity, being qualitatively similar, however, differ greatly in terms of quantity. For example, in the field of the stabilizer astern area characteristics of the recirculation zones are significantly different at various powers N_b. As can be seen from Fig. 3, large values of the power of the burner correspond to large length of the recirculation mixing zones. For 20, 110 and 200 kW burner power the length is 0,026; 0,048 and 0,0945 m, respectively. In this case between themselves and the maximum values of the absolute values of velocity in the areas of recirculation zones are markedly differed.

According to the data obtained for different power burners are also conserved general patterns of mixing of fuel and oxidizer. Fig. 4 and 5 illustrate the typical character of the fields of mass concentrations of methane as an example of the burner 110 kW. Here zones I and II correspond to areas with an excess air and natural gas content, respectively, while zone III - areas in which the mixture is flammable limit. As can be seen, in general, there is a favorable picture of the mixing of fuel and oxidizer in the burner. In a cavity area and the recirculation zone of the stabilizer mixture meets flammable limit.

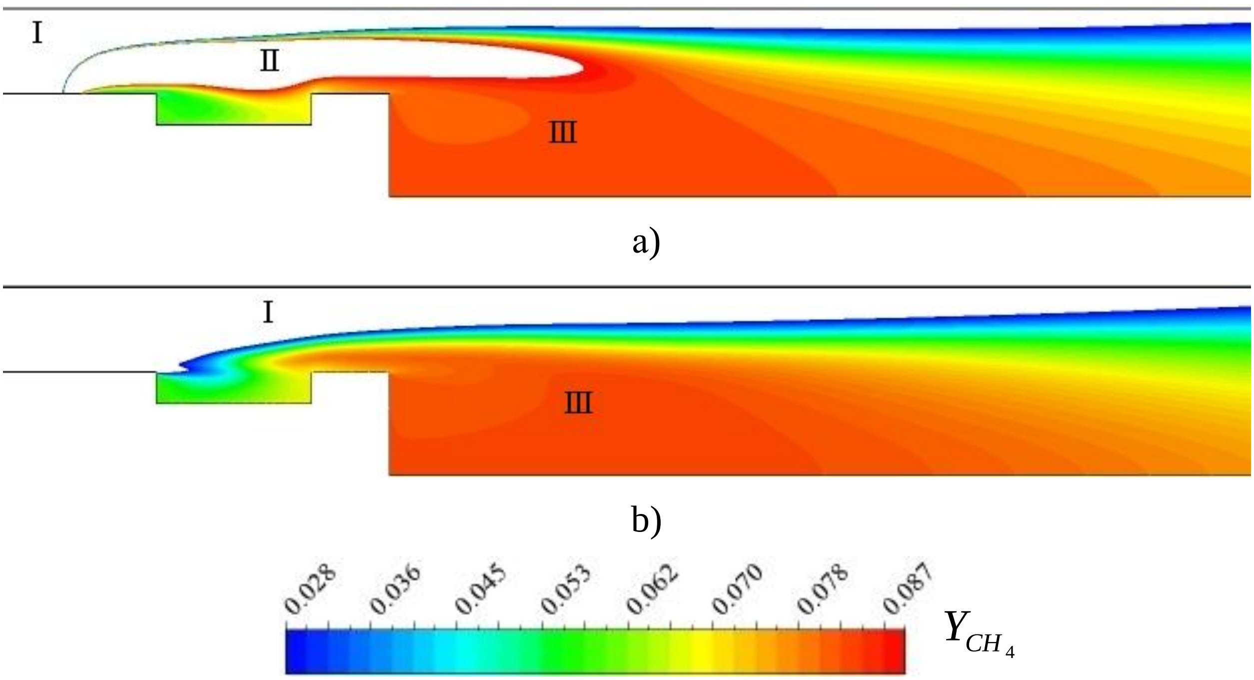


Fig. 4 Fields of mass concentration of methane in the longitudinal section of the cylindrical stabilizer of the burner through the center of the gas supply hole (a) and in the middle between the holes (b) for the burner 110 kW

On the basis of the research identified the rational design parameters for the type series micro-flame cylindrical burners. Table 1 shows the basic geometric characteristics of such devices.

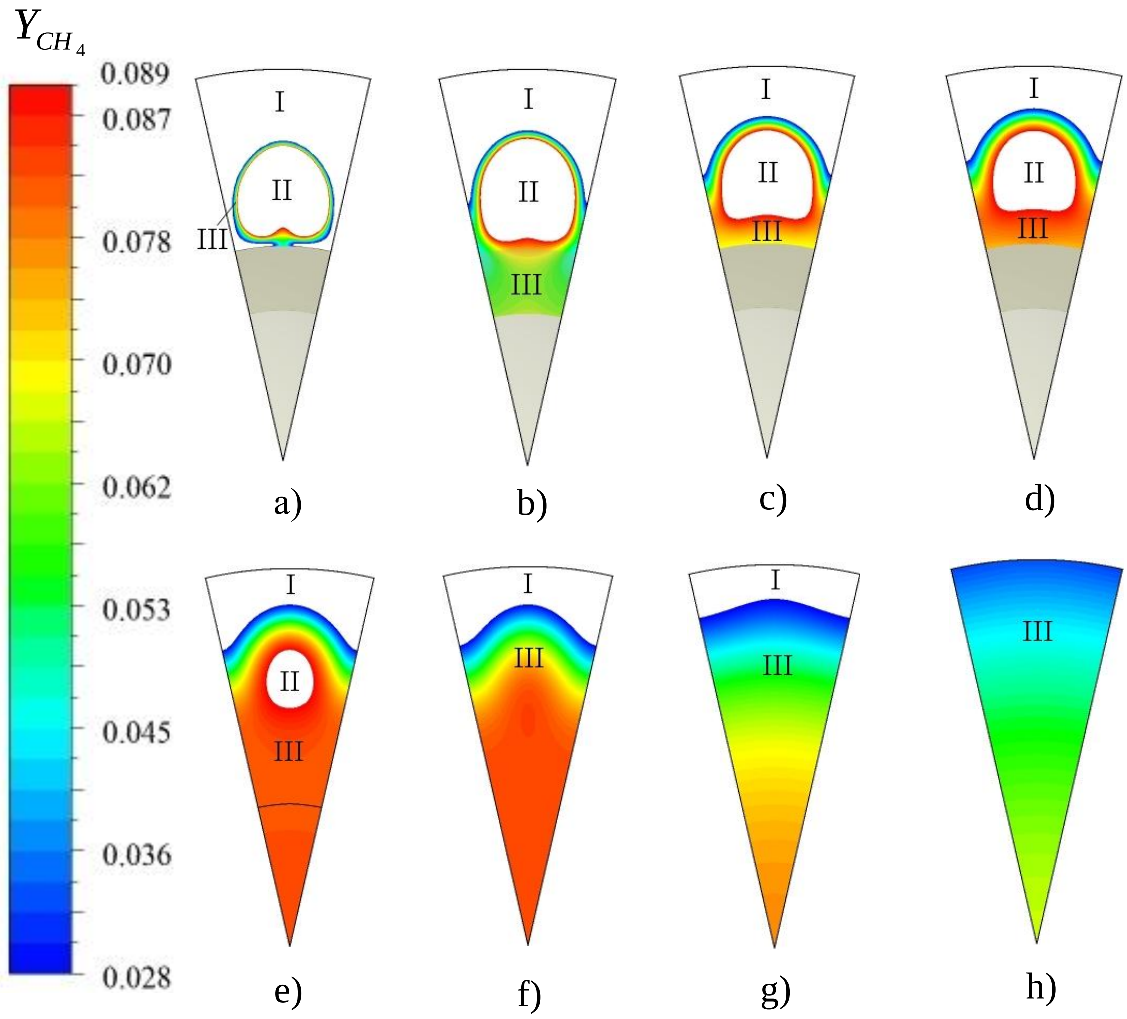


Fig. 5 Fields of mass concentration of methane in the cross sections of the burner located at a distance *z*' from the gas supply holes of the burner 110 kW: a) *z*' = 0,015 m (front wall cavity); b) *z*'= 0,030 m (mid cavity); c) *z*'= 0,045 m (rear wall cavity); d) *z*'= 0,06 m (stabilizer stalling edge); e) *z'* = 0,085 m; f) *z'* = 0,11 m; g) *z'* = 0,21 m; h) *z'* = 0,36 m

As follows from the data in the table, there is quite clearly a strong correlation between the power of the burner and the geometric characteristics of the relevant design, namely, increasing the power of the burner increases the diameter of the cylindrical stabilizer, gas supply holes and decreases relative spacing of their location.

Table 1

Basic geometric characteristics of type series micro-flame cylindrical burners ranging from 20 to 200 kW

N_b, kW	d_{st}, m	d, m	S/d
20	0,02	0,002	3,5
65	0,03	0,0025	3,43
110	0,04	0,003	3,22
155	0,05	0,0035	3,0
200	0,06	0,004	2,94

Conclusions

As a result of carried out research for micro-flame cylindrical burners with rectangular ring-shaped cavity features of the flow and mixing in these devices are identified, and on this basis recommendations are developed on the choice of their geometric characteristics.

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ОСОБЛИВОСТІ ТЕЧІЇ І СУМІШОУТВОРЕННЯ В МІКРОФАКЕЛЬНИХ ЦИЛІНДРИЧНИХ ПАЛЬНИКОВИХ ПРИСТРОЯХ РІЗНОЇ ПОТУЖНОСТІ

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Для типоряду мікрофакельних циліндричних пальникових пристроїв потужністю від 20 до 200 кВт наводяться результати виконаного на основі CFD моделювання комплексу досліджень аеродинаміки і сумішоутворення в даних пристроях. Представлено розроблені рекомендації щодо вибору раціональних конструктивних параметрів розглянутих пальникових пристроїв.

CFD моделювання, циліндричні пальникові пристрої, аеродинаміка, сумішоутворення палива та окислювача

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