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Reduction of noxious substance emissions at the pulverized fuel combustion in the combustor of the BKZ-160 boiler of the Almaty heat electropower station using the "Overfire Air" technology*

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The computational experiments using the "Overfire Air" (OFA) technology at the coal dust torch combustion in the combustor of the BKZ-160 boiler of the heat power plant No. 2 in Almaty have been conducted. The results show a possibility of reaching a reduction of the emission of noxious nitrogen oxides NO_x and minimizing the energy losses. The results of numerical experiments on the influence of the additional air supply on the main characteristics of heat and mass transfer are presented. A comparison with the base regime of the solid fuel combustion when there is no supply of the additional air (OFA = 0 %) has been made.

Key words: heat and mass transfer, combustion, overfire air, computational experiment.

The share of power engineering enterprises in the total volume of the ambient medium pollution by the fuel combustion products is high. The enterprises of heat-and-power engineering, ferrous and non-ferrous metallurgy, oil and gas branches, and machine-building are the most harmful for ecology. Such substances as the carbon oxide, nitrogen oxide, nitrogen dioxide, dust, lead, sulfur dioxide, etc., are exhausted into the atmosphere in Kazakhstan, which harm substantially the living organisms [1–2].

In connection with the fact that the thermoelectric power stations operating on solid fuel are one of the main sources of the atmospheric air pollution by harmful gaseous and dust emissions, the development of the fuel combustion technologies with minimum emissions of the NO_x, SO_x, and ash particles becomes urgent. The coals of Kazakhstan are a good low-sulfur power fuel, and one can reduce to a minimum the harm to the ambient medium at a rational arrangement of the furnace process.

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The problem of minimizing noxious substance emissions into the atmosphere by power engineering enterprises can be solved only by basing on the physical, mathematical, and chemical modeling. In this connection, the numerical experiment becomes one of the most economical and convenient techniques for a detailed analysis of complex physical and chemical phenomena occurring in the furnace chamber. The use of the efficient equipment and advanced program complexes enables the solution of these tasks for specific power plants (thermal power stations, state regional electric stations, etc.) and for any power-plant fuel [3–12].

The OFA method, which is also termed the "Overfire Air" method [13–15], involves the supply of the entire air volume for (primary and secondary) combustion in two stages: 70–90 % of air are fed to the burners, and the remaining amount of air is supplied to the furnace facility above the burner by the overfire air technology (Fig. 1). When the fuel is mixed in the burner with a controlled air flow a combustion zone with a relatively low-temperature, with vitiated air, and enriched with fuel is created in the lower part of the furnace facility, which helps to reduce the formation of the NO_x from the nitrogen contained in fuel (the fuel NO_x).

The air supply by the overfire air method occurs above the main combustion zone and is directed into several air ducts lying on the combustor forward and rear walls above the upper level of burners to ensure a more complete fuel combustion. A relatively low temperature in the afterburning zone enriched by oxygen causes a low formation of NO_x from air (thermal NO_x) [14].

Figure 2 shows the aerodynamic peculiarities of possible methods of the combustion process arrangement using the OFA technology in the combustor with a tangential scheme of the fuel and oxidizer supply. It is seen that the advantage of this method lies in the possibility of ensuring minimum expenses for a wide choice of the arrangement of injecting sources at the rearrangement of the existing regime.

Numerical modeling of the combustion process of solid fuel being in pulverized state was based on the nonlinear differential equations written with regard for chemical reactions and involving the equations of continuity and motion of viscous medium, equations for heat and diffusion propagation for the reacting mixture components and reaction products with regard for thermal radiation and multiphase character of the medium, the equations of the k-ε turbulence model as well as the equation of state and chemical kinetics equations determining the intensity of nonlinear sources of energy and substance [7, 10–11, 16–27].

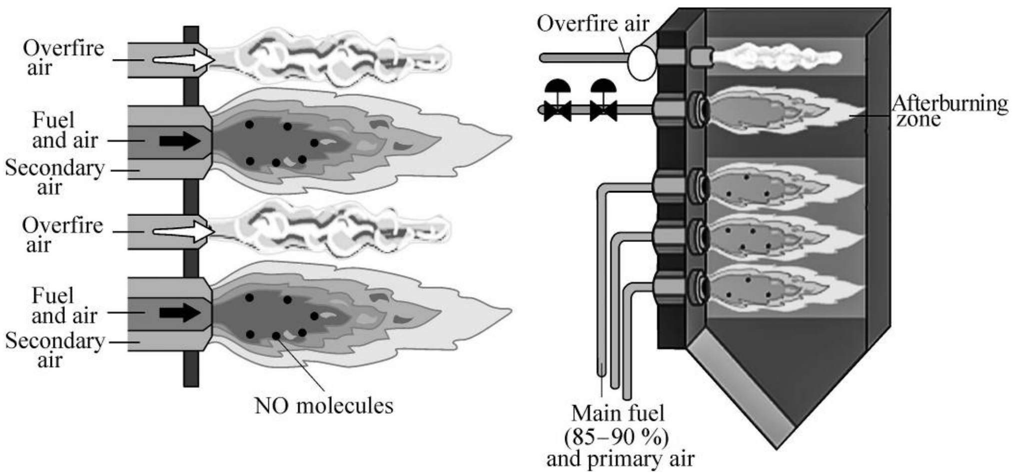

Fig. 1. Different versions of the arrangement of OFA injectors.

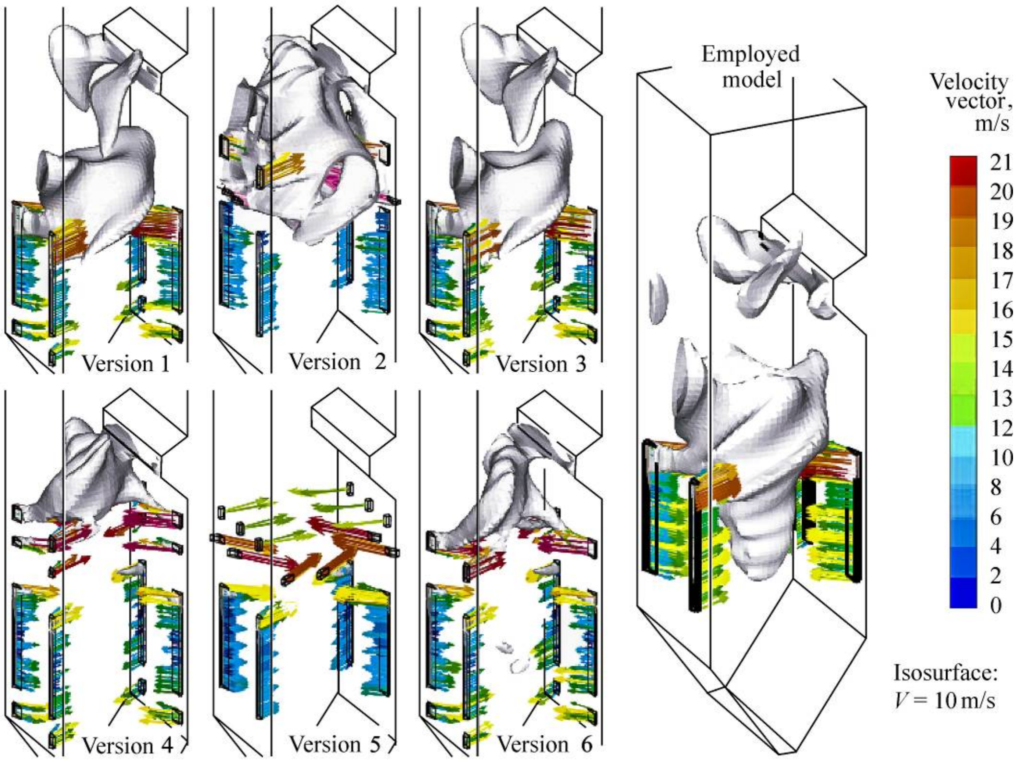

Fig. 2. Aerodynamic pattern of the introduction in the combustor of additional air flows by the Overfire Air method.

The primary injected flows are represented by the air (about 70–90 % of the air total base volume), which is fed to the combustor in a mixture with solid fuel at a relatively low temperature (of the order of 400–600 K). One succeeds here in reaching the formation in the region of burners of a zone rich in fuel, which has a reduced content of oxygen, which contributes to a moderate formation of the fuel NO_x.

The secondary injected flows (about 10–30 % of the air total base volume) are supplied additionally above the combustion zone through special injectors with aerial ports, which are mounted in a plane above the main burners. The location of such extra injectors depends on the configuration of combustion chambers. In this region, the main combustion process is practically terminated. Consequently, a relatively low temperature in the secondary injection region restricts the formation of thermal NO_x.

The operating combustor of the BKZ-160 boiler of the Almaty heat electropower station (HES) No. 2 was chosen for doing numerical experiments on the investigation of the influence of the OFA technology, and the Ekibastuz coal was chosen as the fuel. The combustor of the BKZ-160 boiler of the Almaty HES-2 has the design steam productivity of 160 t/h at the pressure of 9.8 MPa and the steam overheating temperature of 540 °C. The boiler thermal power amounts to 124.4 MW. Four blocks of straight slot burners are located on the lateral sides of the furnace chamber, which are directed along a tangent to the central conditional circle. Two regimes were chosen for the implementation of the OFA technology, namely, when 10 % and 20 % of the air total volume are fed through the injectors in the combustor upper part.

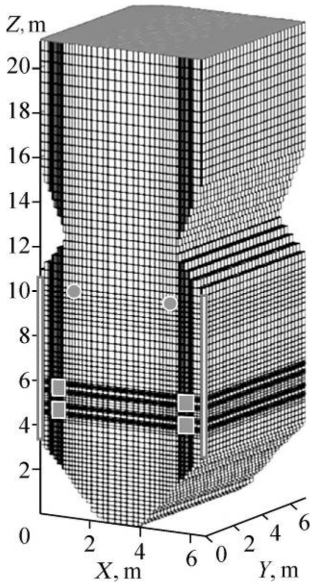

Fig. 3. General view of the furnace chamber of the BKZ-160 boiler of the Almaty thermal power plant 2 and its partition into control volumes.

The entire computational region is generally partitioned for doing the computational experiment by a difference grid into the discrete points or volumes, the continuous field of variables is replaced with discrete values in grid nodes, and the derivatives entering the differential equations are replaced with their approximate expressions via the differences of function values in grid nodes. In the present work, the method of control volume [4, 6, 16–17] was applied for the solution of the posed problem. The difference grid size amounted to 60×75×120 (which corresponds to 540000 grid cells).

Figure 3 shows the general view of the furnace chamber, and Figure 4 presents the flow scheme in the region of the fuel supply (*a*) and in the region of air injection by the OFA technology (*b*) in the combustor cross section. Figure 5 shows the scheme of the arrangement of burner devices by the tangential scheme of the air mixture supply to the furnace chamber, and it also shows the height at which the OFA injectors are mounted together with the distribution of the vector of full velocity in the *YZ* section.

The design characteristics of all parameters necessary for computational experiments on the combustion of the coal dust in the combustor of the BKZ-160 boiler of the Almaty HES-2 are summarized in the Table.

Figures 6–11 show the results of computational experiments on the investigation of the OFA injectors on the temperature and concentration characteristics of the furnace chamber of the BKZ-160 boiler of the Almaty HES.

The application of the OFA technology causes a reduction of the oxygen concentration in the region of the most intense combustion (Fig. 6), which leads to an increase in the flame temperature in this region (Fig. 7) and a decrease in the total coefficient of air excess in this zone.

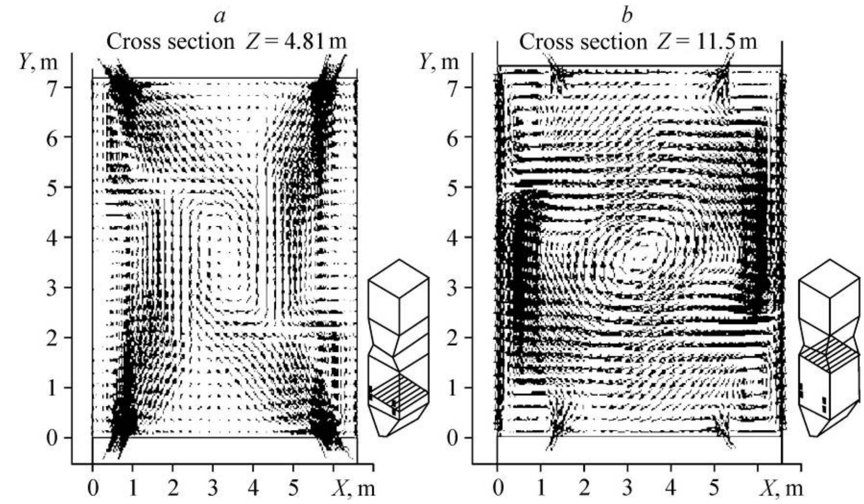

Fig. 4. Velocity field in the region of the location of burner devices (*a*) and in the region of OFA injectors (*b*).

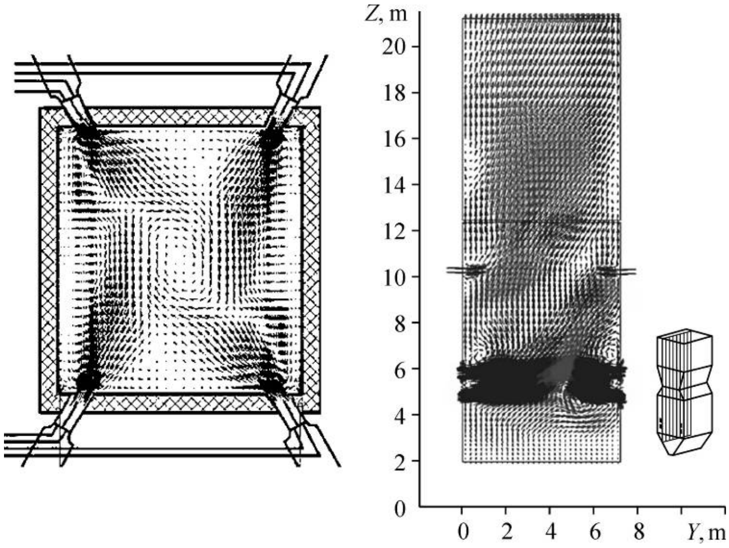

Fig. 5. Scheme of the arrangement of burner devices and OFA injectors in the furnace chamber of the BKZ-160 boiler of the Almaty HES.

As a result of temperature increase, the level of the emissions from the incomplete combustion drops, the velocity of elementary reactions grows, and the quality of mixing increases, which reduces the residence time necessary for mixing the fuel gas and secondary air of combustion. However, this does not lead to an automatic reduction of the level of the NO_x

Table

Design characteristics of the BKZ-160 boiler of the Almaty HES

Name, characteristics, dimensionality	Notation	Value
Fuel expense per boiler, t/h	B	30
Fuel expense per burner, t/h	$B^b = B/Z$	3.787
Combustion heat, MJ/kg	Q_H^p	12.2
Emission of volatiles, %	V^F	32
Diameter of coal particles, m·10^6	d^{par}	60
Air excess coefficient at the outlet	α_{out}	1.27
Air excess coefficient at the burners	α_{b}	0.68
Air inflow into the furnace	$\Delta\alpha$	0.59
Air mixture temperature, °C	T_{a}	250
Secondary air temperature, °C	T_2	380
Tertiary air temperature, °C	T_3	380
Type of employed burners	Slot	
Number of burners, pcs	n_B	8
Number of rows, pcs	N	2
Furnace height, m	$z(H)$	21
Furnace width, m	Y	6.565
Furnace depth, m	X	7.168
Primary air (air mixture) speed, m/s	W_1	25
Secondary air speed, m/s	W_2	40
Secondary air flow rate under norm. cond., m^3/h	–	6000
Coefficient of the secondary air excess	–	0.38
Primary air flow rate under norm. cond., m^3/h	–	4850

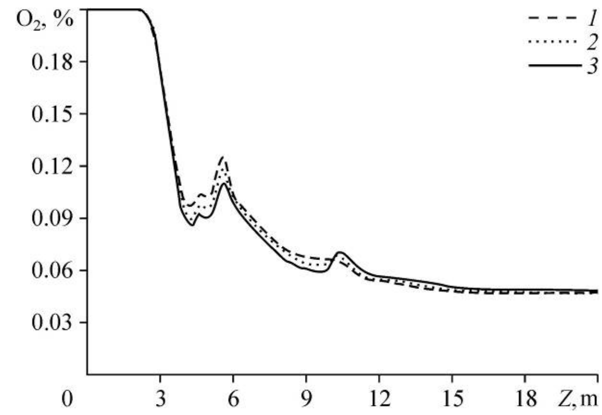

Fig. 6. Distribution of the oxygen concentration over the furnace chamber height.
OFA = 0% (*1*), 10% (*2*), 20% (*3*).

emissions. An efficient reduction of the NO_x emissions may be ensured at the next stage when the air is injected via the OFA.

It is most advantageous to place the OFA injectors in a region located above the main combustion zone, at the maximum possible distance from the narrowest part of combustors. At the extra oxygen supply via the OFA injectors, a further oxidation of the CO moving towards the outlet is observed, and, thus, there occurs the transformation of CO into CO_2. The location of OFA injectors in a region lying above the main combustion zone enables the intensification of the mixing of the OFA air with CO in the common flow of combustible gases. This in turn enables the maximum possible conversion of CO into CO_2 before a significant part of CO leaves the furnace chamber (Figs. 8 and 9).

The results of comparing the base regime of the chamber with a regime when the additional OFA injectors are switched on are illustrated in Figs. 10–11. They show that the highest NO_x concentrations are observed in the lower part of the furnace chamber, which is typical for all furnace kinds. However, unlike the base regime when there are high NO_x concentrations at the combustor outlet, one observes a significant drop of nitrogen oxides at the arrangement of OFA systems when approaching the outlet.

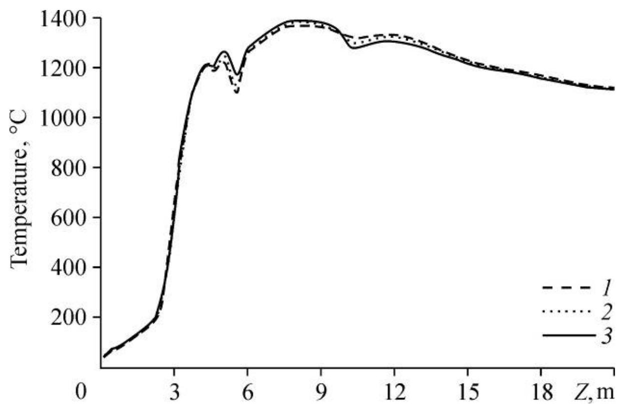

Fig. 7. Influence of OFA injectors on temperature distribution over the furnace chamber height of the BKZ-160 of the Almaty HES 2.
OFA = 0% (*1*), 10% (*2*), 20% (*3*).

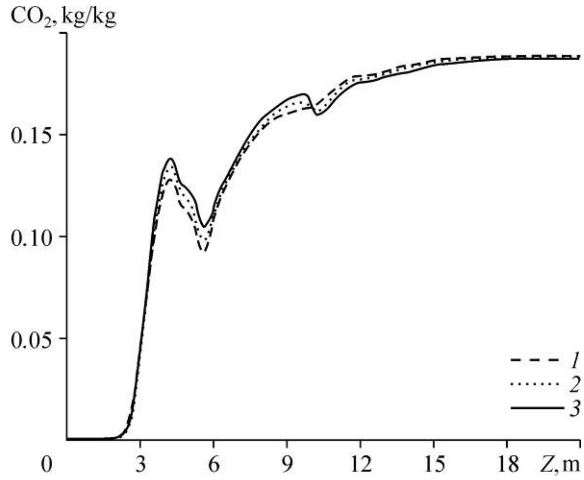

Fig. 8. Distribution of the carbon dioxide concentration (CO_2) over the furnace chamber height.
OFA = 0 % (*1*), 10 % (*2*), 20 % (*3*).

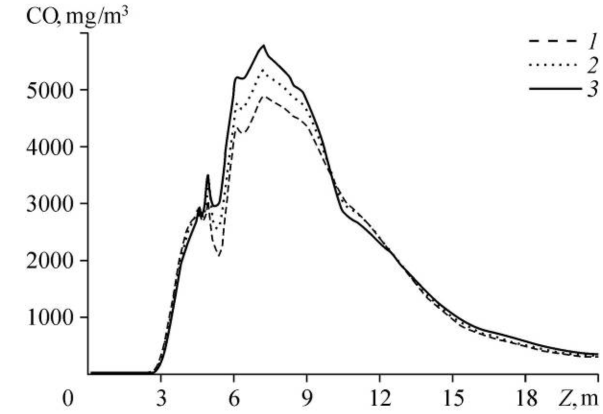

Fig. 9. Distribution of the concentration of the carbon oxide (CO) over the furnace chamber height.
Here and after, cubic meter is under normal conditions: $P = 1$ atm, $T = 298$ K.
OFA = 0 % (*1*), 10 % (*2*), 20 % (*3*).

An especially sharp jump is observed for the NO concentration right in the region of the location of injectors (z = 10.15 m). Two factors affect this. First, the coal combustion in the region of mounting the burner devices takes place at a relative shortage of the oxidizer and the fuel elevated content that is when there occurs the combustion of the air mixture rich in fuel. The formation of fuel NO_x then reduces in the given zone. Second, the processes of the afterburning of air mixture and volatiles take place

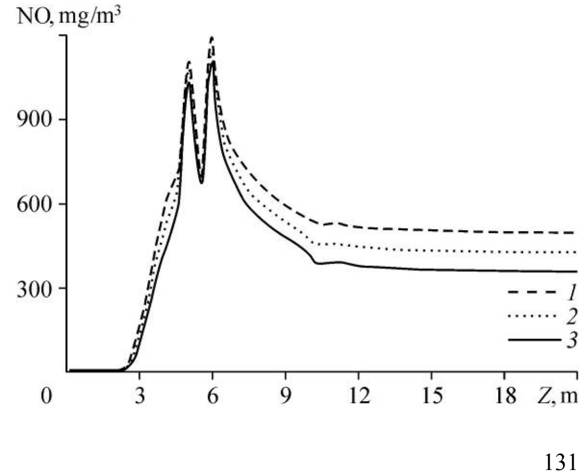

Fig. 10. Distribution of the nitrogen oxide (NO) concentration over the furnace chamber height.
OFA = 0 % (*1*), 10 % (*2*), 20 % (*3*).

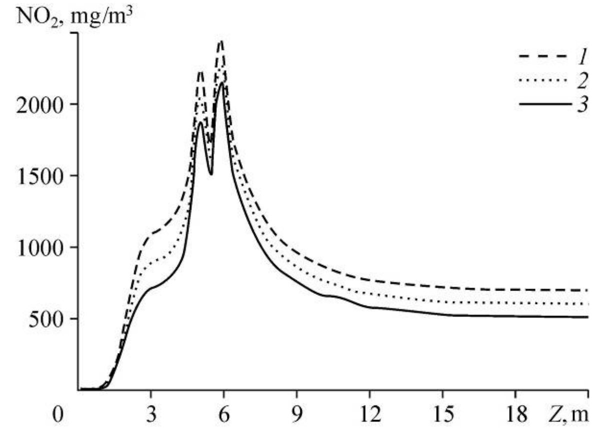

Fig. 11. Distribution of the nitrogen dioxide concentration (NO_2) over the furnace chamber height. OFA = 0% (*1*), 10% (*2*), 20% (*3*).

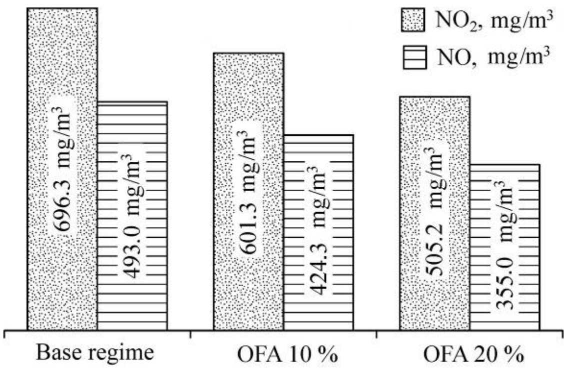

Fig. 12. OFA influence on the emissions of the nitrogen oxides NO and NO_2 at the BKZ-160 combustion chamber outlet.

in the region of OFA injectors. The combustion process is terminated in this region under an observed increase in the flame volume and at a relatively low temperature because of the supply of an additional amount of oxygen from air. Thus, a relatively low combustion temperature in the region of OFA injectors restricts the formation of thermal NO_x. The combination of these two effects just leads to a significant reduction of the NO_x concentration at the outlets of furnace chambers.

Figures 12–13 present the diagrams of the results of numerical investigations on the arrangement of the solid fuel combustion process accounting for the OFA technology and show a reduction of the concentration of nitrogen oxides by 27 % caused by its use at the maximum share of the extra air (OFA = 20 %) as compared to the base regime of fuel combustion (OFA = 0 %).

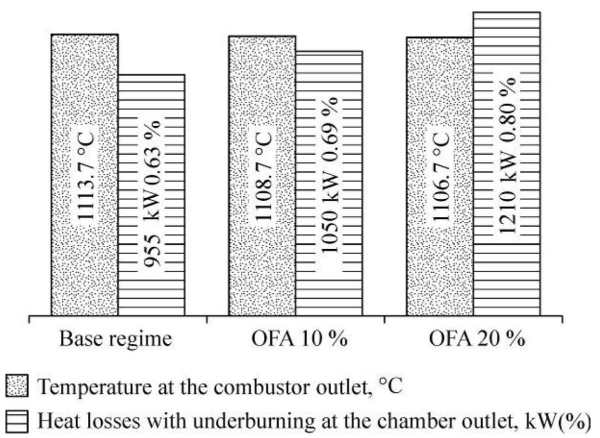

Fig. 13. OFA influence on the temperature at the combustion chamber outlet and on heat losses with underburning.

The results of the conducted numerical modeling of the coal dust torch combustion in the combustion chamber of the BKZ-160 boiler of the thermoelectric power station TEPS 2 at Almaty using the "Overfire Air" method enable us to propose for heat-and-power engineers the newest technologies of a coal pure combustion and reduction of noxious emissions of the nitrogen oxides NO_x.

Computational experiments on the Ekibastuz coal combustion have been conducted for the furnace chamber with a tangential fuel supply by the example of the model of the BKZ-160 boiler of the Almaty HES 2. However, one can use the "Overfire Air" method considered in the work at the execution of similar computational experiments on any operating devices of powerful energy units. This enables an efficient control of fuel combustion processes in actual power installations with a necessary effect on their various parameters, search for the best design and arrangement solutions for burner devices, creation of optimal techniques of combustion of a high-ash coal, and minimization of noxious dust and gas emissions into the atmosphere.

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