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THE USE OF MODERN TECHNOLOGIES IN ORDER TO OPTIMIZE THE HEAT AND MASS TRANSFER PROCESSES IN THE COMBUSTION CHAMBER OF THE KAZAKHSTAN'S INDUSTRIAL BOILERS

*Valeriy MAXIMOV^{*1}, Aliya ASKAROVA¹, Saltanat BOLEGENOVA², Symbat BOLEGENOVA²*

^{*1}Al-Farabi Kazakh National University, Faculty of Physic and Technologies, Department of Technical Physic, Almaty, Kazakhstan

²Scientific Research Institute of Experimental and Theoretical Physics, Almaty, Kazakhstan
E-mail: Valeriy.Maximov@kaznu.kz

The article describes modern technologies to optimize the combustion processes and reduce emissions of harmful substances into the atmosphere. In particular, numerical experiments on the torch combustion of the coal dust prepared by a plasma-thermochemical treatment for combustion have been done using the method of three-dimensional simulation. It is shown that the plasma preparation of coal for combustion enables one to optimize the process, improve the conditions for in flammation and combustion and minimize the emissions of harmful substances. In addition, the computational experiments using the "Overfire Air" (OFA) technology at the coal dust torch combustion in the combustor of the industrial boiler have been conducted. 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.

Keywords: gasification, plasma-fuel systems, Over Fire technology, combustion, harmful substances

Introduction

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.

At present, about 85 % of electricity are generated in Kazakhstan on thermoelectric power stations (TPS), the main fuel of which is the coal. Over 80 % of the coal burnt at TPS are low-grade, for example, such as the Ekibastuz coal whose ash content amounts to 40–50 %. The combustion of low-grade coals is associated with the difficulties of their inflammation and burn-out, an increase of harmful dusty and gaseous emissions (ash, nitrogen and sulfur oxides) [1].

The use of low-grade coals leads to an increase in the mazut and natural gas expenses for the furnace kindling, capturing and stabilization of the pulverized coal torch combustion, and the environmental situation worsens. Such substances are exhausted into the atmosphere in Kazakhstan, which harm substantially the living organisms. 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 [2].

It is adopted in the world practice to enrich the coals prior to their combustion. One cannot, however, expect the enrichment of coals in the volumes needed for TPS's of Kazakhstan and Russia because of a high price of enrichment, which amounts to about 10 U.S. dollars per one ton of coal [3]. As a result of the enrichment, one can reduce the ash content and humidity of coals, whereas it is impossible to increase the emission of volatiles (hard coals and anthracite have the emission of volatiles of 4 – 12 %) by enrichment.

To improve the inflammation and stabilize the combustion of low-grade coals with a low emission of volatiles and a high ash content there are additional measures, which reduce mainly to a grind refinement (up to $R_{90} = 6 - 8 \%$, where R_{90} is the rest of coal dust at the bolting through a bolter with a cell of 90 μm size), the heating of the mixture saturated with air (up to 350 °C) and of the secondary air (up to 400 °C), supply of pulverized coal of high concentration (up to 50 kg/kg) with its subsequent dilution, and joint combustion of coal and mazut or natural gas [4]. All the above measures possess substantial shortcomings, which reduce the efficiency of using the fuel and the reliability of the operation of the TPS furnace aggregates with a simultaneous reduction of their environmental indices.

Various methods are developed to increase the efficiency of using the fuel. The works dealing with the fuels inflammation with the aid of a low-temperature plasma [5–8] have enjoyed a wide development. To reduce the fraction of the mazut and natural gas in fuel balance of thermal power plants and to bring down the harmful dust-gas emissions a plasma technology of the inflammation, thermochemical preparation and combustion of coals and the plasma-fuel systems (PFS's) implementing it were developed [4–6]. As follows from the very definition of the system, the PFS generally represents a burner device with a plasmatorch. The processes of the plasma thermochemical preparation of solid fuels for combustion are realized in the PFS.

At the use of a plasma activation of the pulverized coal flow the input parameters employed in computations differ from those existing in practice at a conventional arrangement of the pulverized coal torch combustion. A torch of the reacting fuel mixture enters the combustor, which causes an alteration of the main parameters of the combustion process. In this connection, a complex investigation of the work process of the furnace chamber with allowance for the influence of the fuel thermochemical preparation, including the numerical simulation of processes occurring within the combustor volume, becomes especially urgent.

Description of the Technologies and results of the numerical experiments

The plasma thermochemical preparation of low-grade coal

The plasma thermochemical preparation of coal for combustion consists of the heating by a plasmatorch at an oxygen deficiency in the pulverized coal flow in a special chamber up to a temperature exceeding the temperature of the self-inflammation of a given coal. In this case, there occurs a practically complete emission of volatiles and a partial combustion and/or gasification of the coal carbon. As a result, the obtained fuel mixture or the highly reactive two-component fuel (HRTF) consisting of the combustible gas and coke rest ignites at its mixing with a secondary air and stably burns without using a pulverized coal torch for stabilization even in a cold furnace of the backup high-reaction fuel (mazut or natural gas).

The use of various types of burners does not cause the differences in the mechanisms of the process of the plasma thermochemical treatment of coal for combustion. The use of PFS enables one to eliminate from the TPS fuel balance the mazut, which is conventionally used for the lighting of boilers [6-8].

The method of thermochemical plasma preparation of coal for combustion has been tested successfully on several thermal power stations, which confirms its efficiency [8]. However, one needs the development of special techniques for computing the burner devices for a wide introduction of plasma technology of the coals mazut-free inflammation, which will make it possible to estimate prior to experiment the main parameters of the processes occurring in the volume of a burner supplied with a plasmatorch, obtain the fuel mixture composition at the furnace inlet, and compute the characteristics of the heat and mass transfer within the combustor of the TPS boiler. The use of new computer technologies for simulation has enabled one to carry out the computations of these processes [9–14].

The present part of the paper deals with the numerical investigation of the plasma source influence on thermochemical conversions of the aeromixture and its combustion by the example of the combustion of the high-ash coal in the furnace of the BKZ-430 boiler of the Almaty TPS-2. Thus, the investigation task included the computation of combustion processes in the furnace of a boiler supplied with the conventional pulverized coal burners with a mazut sprayer and the PFS (Fig. 1). Three regimes of the boiler operation: the conventional one (using six pulverized coal burners) and with a plasma activation of combustion (with a replacement of three and six pulverized coal burners with the PFS's) were chosen for numerical investigations. Two computer programs were used in computations: the one-dimensional one – “Plasma-Coal”, which accounts for a detailed mechanisms of the kinetics of thermochemical conversions of the fuel in two-phase flow with a plasma source, and the three-dimensional one – “FLOREAN” [15-16], which accounts for the furnace actual configuration and the kinetics of the process of the combustion of coal particles by a simplified kinetic scheme. The parameters of a high-reaction two-component fuel (the synthesis-gas and coke rest) obtained from the aeromixture in the PFS were computed using the code “Plasma-Coal” [6]. They were the initial parameters for the three-dimensional computation of the furnace of the BKZ-420 boiler supplied with a PFS, which were done by the code “FLOREAN”. The same code was used also for the computations of the conventional regime of coal combustion in the furnace of boiler BKZ-420.

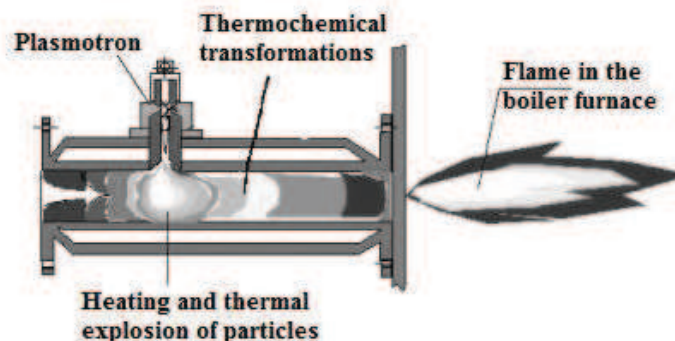


Figure 1. Plasma-fuel system scheme

The furnace of the BKZ-420 boiler of the power unit with power of 300 MW, vapor production of 420 t/h is equipped with six pulverized coal burners. The burners are mounted oppositely in two rows, each row contains three burners. The fuel consumption per a burner amounts to 12000 kg/h. The Ekibastuz coal is used as the main fuel, its humidity $W^w = 7\%$, ash content $A^w = 40.9\%$, and the organic mass composition, mass. %: $S^w = 0.8$, $C^w = 41.1$, $H^w = 2.8$, $O^w = 6.6$, $N^w = 0.8$. The fuel combustion heat amounts to 15.87 MJ/kg, the emission of volatiles is 30 %. The grinding fineness of the coal dust R_{90} amounts to 14.3 %. The air excess coefficient at the furnace outlet amounts to 1.25, in burners it equals 1.15, the air cup to the furnace amounts to 0.1.

While replacing the design burners with the vortex PFS's (Fig. 1) with a chamber for electrothermochemical fuel preparation 0.73 m in diameter one employs a plasmatorch with 100 kW power. The chamber wall temperature was assumed equal to 700 K. The mean-mass diameter of coal particles was 60 μm ($R_{90} = 14.3\%$), the original aeromixture temperature at the PFS inlet remained the same as at the inlets of the main burners and was equal to 423 K, the coal consumption via the PFS was 7.3 t/h. The thermal efficiency of the PFS based on experimental data was taken to equal 90 %. The results of the PFS numerical simulation are summarized in Tab. 1.

Table 1. Main characteristics of the HRTF at the PFS outlet

CO	H ₂	CH ₄	CO ₂	H ₂ O	N ₂	O ₂	NO, mg/m ³	X _C , %	V _g , m/s	T _g , K	t _g , s
Volumetric, %											
11.04	2.17	0.22	13.53	1.93	0.55	0.13	7.5	67.6	42.1	1076	0.016

These data taken for the PFS outlet section have been used as the input data for the three-dimensional simulation of the furnace of the power boiler BKZ-420 of the Almaty TPS-2, three and six burners of which were virtually reequipped into the PFS's.

Figures 2 a, b, c show the full velocity vectors in the combustor cross sections for the conventional coal combustion in the burners location plane and the cross sections supplied with three and six PFS's.

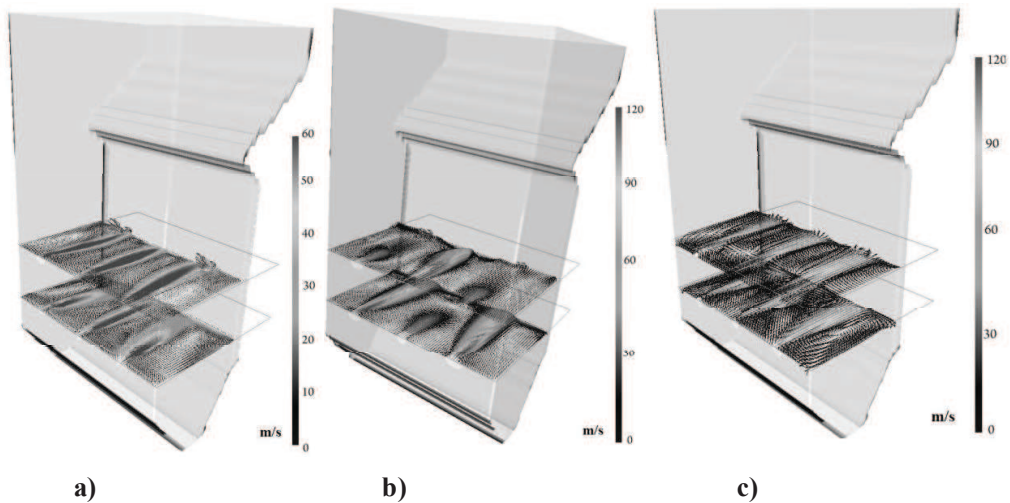
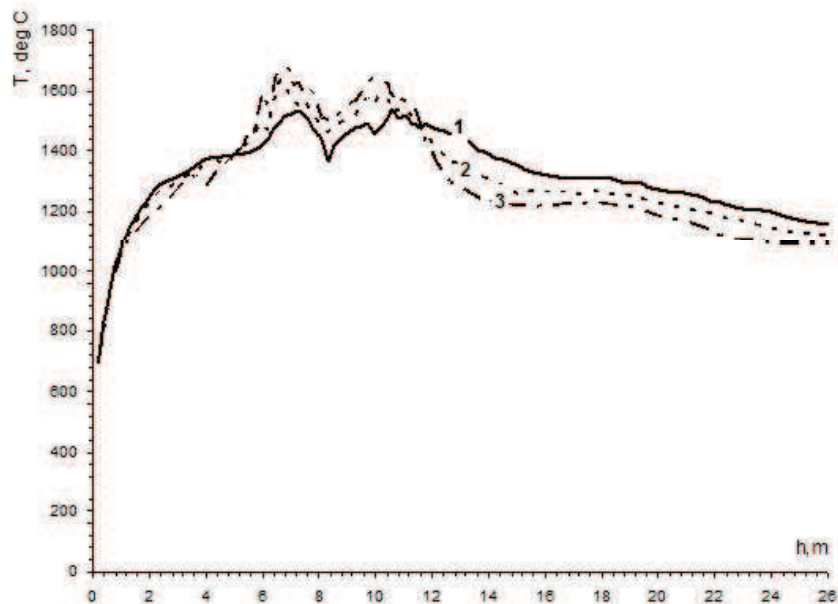


Figure 2. Field of a full speed vector in the sections of torches: a) Conventional coal combustion; b) with three PFS's; c) with six PFS's

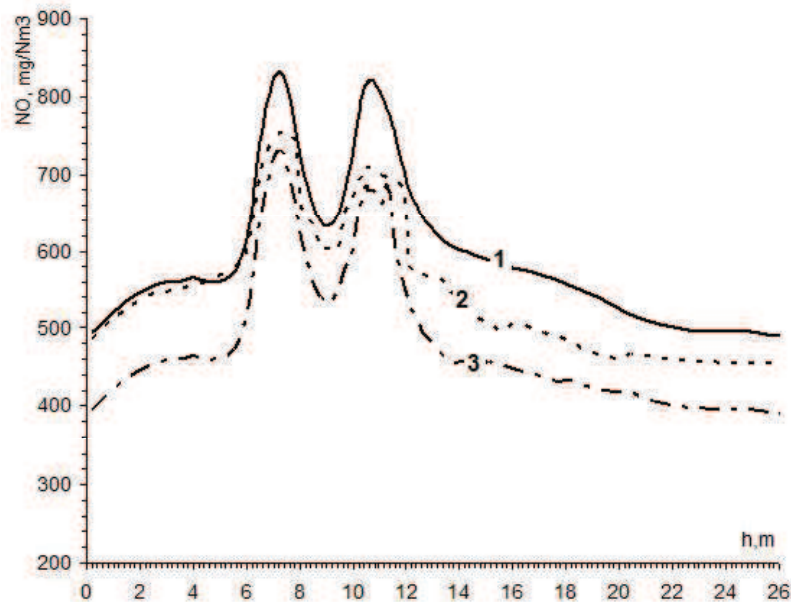
An analysis of the obtained velocity fields has shown that the pulverized coal flow activation affects significantly the flow field, namely the reacting jet propagation in the furnace volume, the admixing processes in the jet, the sizes and shape of torches. One observes a substantial difference in the distribution of pulverized coal flows entering the furnace through the conventional burners and through the PFS. The main reason for the alteration in the distribution of velocities in the furnace space is an increase in the velocity of the fuel mixture supplied to the combustor (the two-component high-reaction fuel). With increasing number of the PFS's that is of the thermochemically activated fuel flows, the torch core shifts to the symmetry center of the furnace chamber, and one observes a clearer pattern of the motion of vortex flows from the PFS. At the location of the flows collision with opposite wall, the dynamic pressure transforms to a static pressure as a result of deceleration. Under the action of the formed pressure jump, the general flow diverges upstream and downstream within the furnace chamber with elevated velocities. The mass and heat exchange intensify at a collision and turbulization of flows, and the resulting enhancement of the mixture formation and heating speed up the combustion process.

Figures 4 and 5 show the variations of the temperatures and NO concentrations over the combustor height, which were computed for three versions of coal combustion with a preliminary plasma activation of the coal in a PFS and with a conventional one. It is seen that the temperatures over the combustor height, which were computed for the coal combustion activated by plasma (Fig. 3, curves 2 and 3) are mainly below the temperatures calculated for the conventional regime of the coal combustion (Fig. 3, curve 1). There is, however, a zone (the combustor lower and upper rows of burners), in which the combustion temperature of the coal with plasma activation is above the coal combustion temperature in the conventional regime. This phenomenon may be explained by the PFS influence, which cause an earlier inflammation of the mixture saturated with air and the corresponding shift of the flame front towards the PFS mouth.



1 – the conventional regime of coal combustion; 2 – three plasma activated flows; 3 – six plasma activated flows

Figure 3. Variation of temperatures over the combustor height



1 – the conventional regime of coal combustion; 2 – three plasma activated flows; 3 – six plasma activated flows

Figure 4. Variation of the NO concentrations over the combustor height

One observes also the PFS influence on the formation of NO (Fig. 4) over the combustor height. Values of the NO concentration over the combustor height are much lower in the case of the combustion of the coal with its plasma activation. Note that the use of the PFS reduces the NO concentration (Fig. 4, curves 2, and 3) even in the combustor lower part (below the PFS location level). This phenomenon is explained by a suppression of the formation of fuel nitrogen oxides inside the PFS. The fuel nitrogen is released into the gaseous phase at the coal heating together with the volatiles inside the PFS. Because of the oxygen deficiency in the aeromixture a molecular nitrogen forms, which is also confirmed by a low level of the NO concentration (7.5 mg/m^3) at the PFS outlet, and, as is known, the fuel nitrogen is the main source of the nitrogen oxides forming at the combustion of coal in the process of its torch combustion.

The “Overfire Air” technology

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.

The OFA method, which is also termed the “Overfire Air” method [17], 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. 5). 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).

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 $k-\varepsilon$ turbulence model as well as the equation of state and chemical kinetics equations determining the intensity of nonlinear sources of energy and substance [18-27].

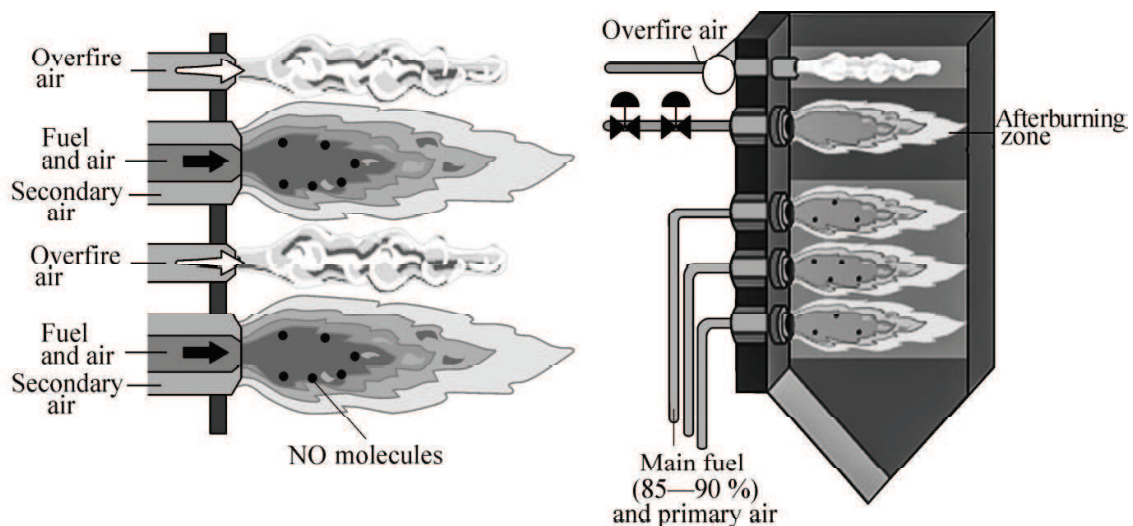


Figure 5. Different versions of the arrangement of OFA injectors

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.

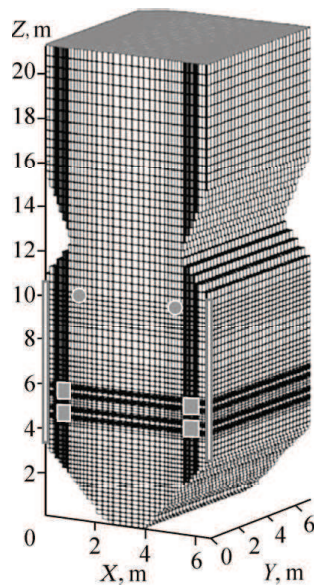


Figure 6. General view of the furnace chamber of the BKZ-160 boiler of the Almaty thermal power plant 2 and its partition into control volumes

The application of the OFA technology causes a reduction of the oxygen concentration in the region of the most intense combustion, which leads to an increase in the flame temperature in this region and a decrease in the total coefficient of air excess in this zone. 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 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 CO₂ before a significant part of CO leaves the furnace chamber.

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. 7–8. 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.

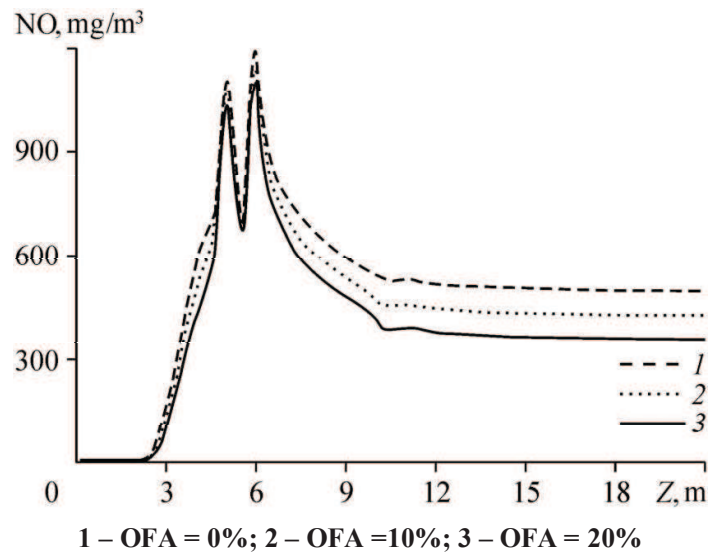


Figure 7. Distribution of the nitrogen oxide (NO) concentration over the furnace chamber height

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 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.

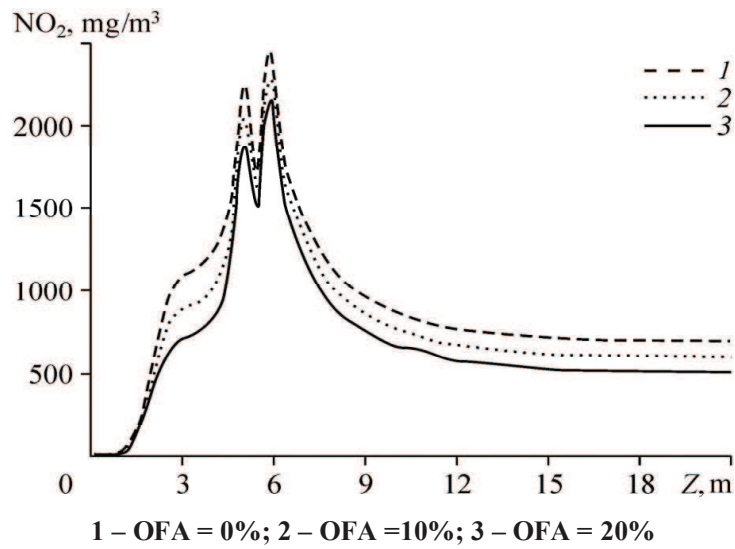


Figure 8. Distribution of the nitrogen dioxide (NO₂) concentration over the furnace chamber height

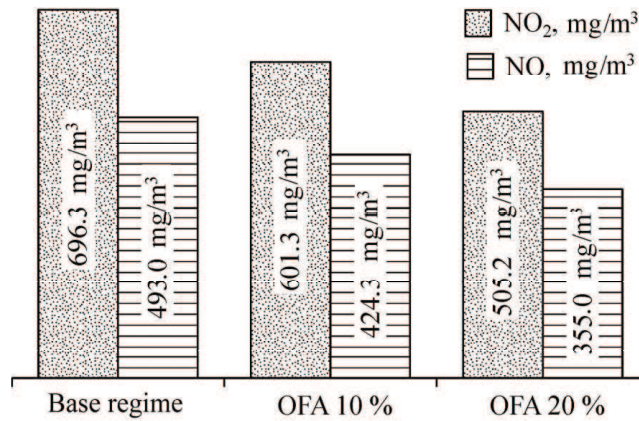


Figure 9. OFA influence on the emissions of the nitrogen oxides NO and NO₂ at the BKZ-160 combustion chamber outlet

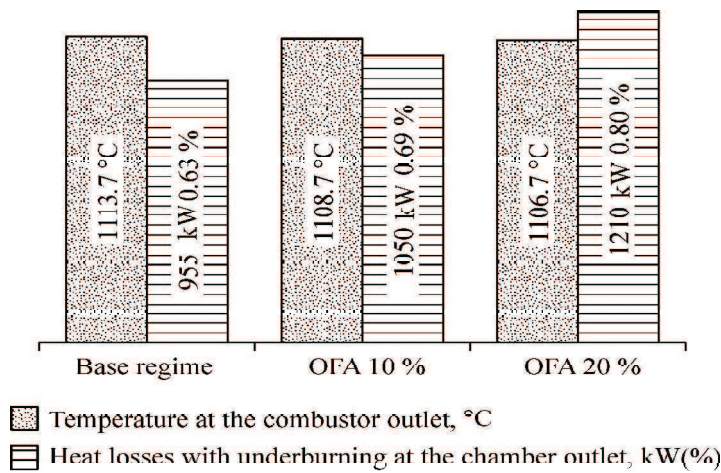


Figure 10. OFA influence on the temperature at the combustion chamber outlet and on heat losses with underburning

Figures 9–10 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 %).

Conclusions

A comparative numerical investigation of the conventional coal combustion and the coal combustion in a furnace supplied with a PFS, which has been conducted in the work, shows that the plasma thermochemical treatment of the coal prior to its combustion enables one to optimize the process, improve the inflammation and combustion conditions, minimize the emissions of harmful substances into atmosphere. The application of the PFS technology will enable a reduction of the equivalent fuel expense per 1 kWh of the generated energy by 10–15 gram of the equivalent fuel, which is equivalent to the 1.5–3 % fuel saving or to an increase in the efficiency of electricity generation by 0.5–1 %. A wide application of the PFS technology carries in itself an important social-economic effect and will make it possible not only to improve the environmental situation in regions near the TPS, optimize the process of the combustion of energy fuels, but also to raise the level of the culture of the TPS workers at the expense of the application of a more progressive and environmentally clean technology of the inflammation and combustion of solid fuels.

In addition, 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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Nomenclature

X_C – coal gasification degree;

V_g – the flow velocity, m/s;

T_g – the temperature of the HRTF flow, [K];

t_g the time of fuel residence in the PFS [s].

References

- [1] Askarova, A.S., Messerle, V.E., *et al.*, Numerical Simulation of the Coal Combustion Process Initiated by a Plasma Source, *Journal of Thermophysics and Aeromechanics*, 21 (2014), pp.747-754
- [2] Askarova, A.S., Karpenko, E.I., *et al.* Mathematical modeling of the processes of solid fuel ignition and combustion at combustors of the power boilers, *Proceedings, 7th International Fall Seminar on Propellants, Explosives and Pyrotechnics. Theory and Practice of Energetic Materials*, Xian, China, 2007. Vol. 7. pp. 672-683
- [3] Karpenko, E.I., Messerle, V.E., *et al.* Plasma enhancement of combustion of solid fuels, *Journal of High Energy Chemistry*, 40 (2006), 2, pp.111-118
- [4] Messerle, V.S., Peregudov, V.S. Ignition and Stabilisation of Combustion of Pulverised Coal Fuels by Using Thermal Plasma, In: *Investigation and Design of Thermal Plasma Technology*, Cambridge Interscience Publishing, London, 1995, pp. 323-343
- [5] Lockwood, F.Ch., Messerle, V.E., *et al.* Three-dimensional computation of partially gasified solid fuel in the furnace of the PK-39-II boiler of the Refтин regional TPS, *Gorenie i Plasmokhimiya*, 6 (2008), 2, pp. 122–130
- [6] Gorokhovskiy, M., Lockwood, F.C., *et al.* Plasma technologies for solid fuels: experiment and theory, *Journal of Energy Institute*, 78 (2005), 4, pp. 157–171
- [7] Messerle, V.S., Ustimenko, A.B. *Plasma Inflammation and Combustion of Solid Fuel. (Scientific and Technological Foundations)*, Palmarium Academic Publishing, Saarbrücken, Germany, 2012
- [8] Karpenko, E.I., Messerle, V.E., *et al.* Using plasma-fuel Systems at Eurasian coal-fired thermal power stations, *Thermal Engineering*, 56 (2009), 6, pp. 456–461
- [9] Askarova, A., Gorokhovskiy, M., *et al.* Stochastic simulation of the spray formation assisted by a high pressure, *Proceedings (Liejin Guo)*, 6th International Symposium on Multiphase Flow, Heat Mass Transfer and Energy Conversion, Xian, China, 2010. Vol. 1207, pp. 66-73
- [10] Askarova, A., Maximov V., *et al.* Numerical Modeling of Pulverized Coal Combustion at Thermal Power Plant Boilers, *Journal of Thermal Science*, 24 (2015), 3. pp. 275-282
- [11] Bolegenova, S., Maximov, V., *et al.* Application of 3D modelling for solving the problem of combustion coal-dust flame, *Bulgarian Chemical Communications*, 48 (2016), E, pp. 236-241

- [12] Messerle, V. E., Maximov, V. Yu., *et al.* Numerical simulation of pulverized coal combustion in a power boiler furnace, *High temperature*, 53 (2015), 3, pp. 445-452
- [13] Askarowa, A., Buchmann, M.A. Structure of the flame of fluidized-bed burners and combustion processes of high-ash coal, *Proceedings*, 18th Dutch-German Conference on Flames, Berlin, Germany, 1997, Vol. 1313, pp. 241-244
- [14] Vockrodt, S., Leithner, R., *et al.* Firing technique measures for increased efficiency and minimization of toxic emissions in Kasakh coal firing, *Proceedings*, 19th German Conference on Flames, Combustion And Incineration, Germany, 1999, Vol. 1492, pp. 93
- [15] Müller, H. *Numerical calculation of three-dimensional turbulent flows in steam generators with heat transfer and chemical reactions on the example of the SNCR process and coal combustion*, VDI-Verlag, No 268, 1992 (in German)
- [16] Leithner, R., Müller, H. CFD Studies for Boilers, *Proceedings*, Second M.I.T. Conference on Computational Fluid and Solid Mechanics, Cambridge, UK, 2003, p.172
- [17] Askarova, A., Maximov, V., *et al.* 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, *Thermophysics and Aeromechanics*, 23 (2016), 1, pp. 125-134
- [18] Bolegenova, S., Beketayeva, M., *et al.* 3-D Modeling of Heat and Mass Transfer during Combustion of Solid Fuel in BKZ-420-140-7C Combustion Chamber of Kazakhstan, *Journal of Applied Fluid Mechanics*, 9 (2016), 2, pp. 699-709
- [19] Leithner, R., Maximov, V., *et al.* Computational modeling of heat and mass transfer processes in combustion chamber at power plant of Kazakhstan, *Proceedings*, MATEC Web of Conferences, 20th International Conference on Circuits, Systems, Communications and Computers, Corfu, Greece, 2016, 10.1051/mateconf/20167606001
- [20] Askarova, A., Bolegenova, S., *et al.* 3D modelling of heat and mass transfer processes during the combustion of liquid fuel, *Bulgarian Chemical Communications*, 48 (2016), E, pp. 229-235
- [21] Bolegenova, S.A., Maximov, V.Y., *et al.* Computational method for investigation of solid fuel combustion in combustion chambers of a heat power plant, *High temperature*. – 5 (2015), 5, pp. 751-757
- [22] Heierle, E.I., Maximov, V.Ju., *et al.* CFD study of harmful substances production in coal-fired power plant of Kazakhstan, *Bulgarian Chemical Communications*, 48 (2016), E, pp. 260-265
- [23] Askarova, A., Bolegenova, S., *et al.* Mathematical modeling of heat and mass transfer in the presence of physical-chemical processes, *Bulgarian Chemical Communications*, 48 (2016), E, pp. 272-277

- [24] Beketayeva, M., Bolegenova, S., *et al.* Numerical experimenting of combustion in the real boiler of CHP, *International Journal of Mechanics*, 7 (2013), 3, pp. 343-352
- [25] Lavrichsheva, Ye., Leithner, R., *et al.* Combustion of low-rank coals in furnaces of Kazakhstan coal-firing power plants, *Proceedings*, 6th International Conference on Heat Transfer, Thermal Engineering and Environment, Rhodes, Greece, 2009, pp. 497-502
- [26] Bekmukhamet, A., Gabitova, Z., *et al.* Using 3D modeling technology for investigation of conventional combustion mode of BKZ-420-140-7c combustion chamber, *Journal of Engineering and Applied Sciences*, 9 (2014), 1, pp. 24-28
- [27] Ospanova, Sh., Beketayeva, M., *et al.* Numerical modeling of turbulence characteristics of burning process of the solid fuel in BKZ-420-140-7c combustion chamber, *International Journal of Mechanics*, 8 (2014), pp. 112-122