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TECHNOLOGY FOR REDUCTION OF NITROGEN OXIDE EMISSIONS AT PULVERIZED COAL BURNING

To assess the influence of thermochemical preparation of anthracite on the formation of nitrogen oxides, a 3D numerical model of the TPP-210A boiler's furnace has been created for standard and modified burners. The calculations have showed a decrease in NOx concentration along the vertical extent of the furnace and in the amount of unburnt coal for the modified burners as compared with the standard ones.

Keywords: nitrogen oxides, anthracite, burner, and coal thermochemical treatment.

Cooperation between Ukraine and the European Energy Community is aimed at reaching high technological and environment indices in the field of thermal engineering by means of construction of greenfield or rehabilitation of existing coal-based generating units using pure coal technologies.

Thermochemical coal treatment (TCP) before combustion in the boiler furnace is one of technologies for flare coal boilers. It has been implemented in the boiler furnace TPP-210A (3A Trypillia TES) and showed improved burning process. Other researchers based on results of their tests [1] have reported possibility of reducing emissions of nitrogen oxides using TCP if the content of volatile substances in coal > 13%. In order to show a TCP effect on concentration of nitrogen oxides it is necessary to replace at least four of six burners in the furnace of TPP-210A boiler for anthracite burning. Currently, the four burners have been manufactured to be installed on the boiler of Trypillia TES. To estimate a reduction of nitrogen oxide emissions using TCP burners using *ANSYS Fluent* software, preliminary comparative computations have been done for two options of burners.

The TPP-210A boiler works on anthracite and consists of two bodies, its furnace has a neck to create conditions for quick removal of liquid slag. Two methods for burning of pulverized anthracite were chosen for comparison: the design method for the TPP 210A boiler using standard vortex burners with pulverized coal supply with primary air and a separate channel for supply of secondary air (Fig. 1) and the TCP method. The design scheme and distribution flows are showed in Fig. 2. Detailed description of the method discussed is given in [2—4].

Further, to determine the effect of TCP method [3] on the furnace performance, the comparative numerical analysis has been made using ANSYS FLUENT software for the operation of TPP-210A boiler equipped with standard burners for combustion of pulverized coal and TCP burners. The simulation program provides computations for the processes of gas and pulverized anthracite combustion, two-phase flow and combined con-

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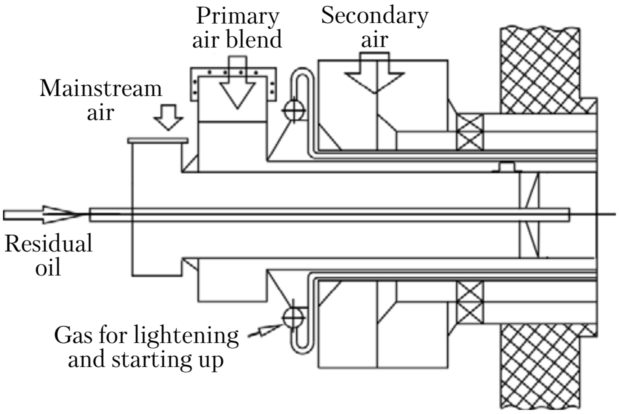

Fig. 1. Scheme of standard burner for TPP-210A boiler

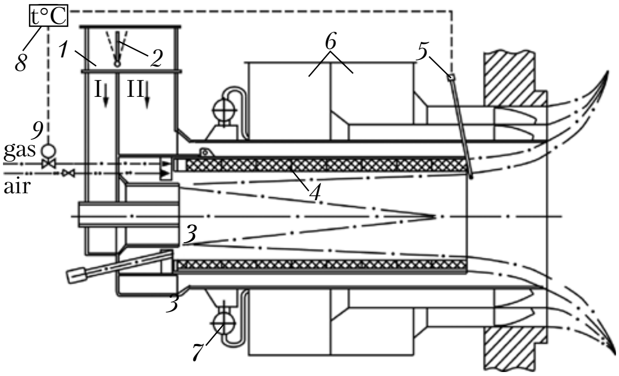

Fig. 2. Configuration of TCP burner for TPP-210A boiler: *1* — pulverized coal burner box; *2* — butterfly damper; *3* — incendiary device; *4* — muffle chamber for pulverized coal thermal treatment; *5* — temperature sensors; *6* — secondary-air burner box; *7* — existing gas collector; *8* — temperature controller; *9* — controller of gas feed for TCP

vection and radiation heat transfer in the object in question. Additionally, in the post-processing mode, the formation of nitrogen oxides has been computed.

INPUT DATA FOR COMPUTATIONS

The input data are based on information from technical specifications of TPP-210A boiler of the Trypillia TES and standard method for boiler thermal design [5]. Configuration of design area for the furnace of two-chamber boiler with removal of liquid slag is given in Fig. 3.

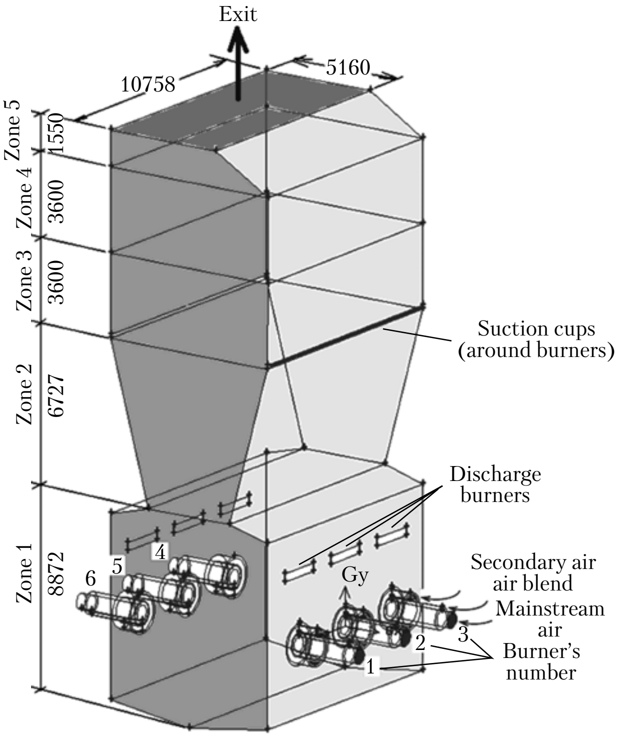

Fig. 3. Geometry of furnace of TPP-210A boiler

The estimated area is divided into 5 zones and limited with walls and furnace exit surface. In the 1st zone, there are six burners to which air mix and secondary air are fed; the 5th zone ends with the narrowest neck in the area of aerodynamic nose. The simulation of flow U-turn in the area of neck significantly complicated the process, with the reverse flows distorting the results at the exit from estimated area. The 1st zone wall surface includes the orifice for slag discharge.

To simulate the processes in the furnace, the boundary conditions on the walls were set by temperatures obtained from the zonal thermal design by standard method [5]. The results are obtained with slag and coal dust deposition on the surfaces taken into account (Table 1). For the 2nd—5th zones in the model they are approximated by linear dependences on longitude coordinates.

In addition to component consumption in the burners the model takes into account the supply of drying agent (air) to the furnace through waste nozzles and air suckers located around burner flanges and at the inlet to the 3rd zone. The parameters based on data of thermal design for TPP-210A boiler of the Trypillia TES in nominal mode are given in Table 2.

Anthracite having a lower combustion heat per as-fired fuel is considered as fuel Q^r_i = = 24.5 MJ/kg. The technical analysis of as-fired fuel and coal element composition is presented in Tables 3 and 4.

Coal particle size composition is assumed to be described by Rosin-Rammler distribution with an exponent 1.1 within range of 5—205 μm and average size of 40 μm. The nitrogen content is assumed to be equally divided between the volatile and solid fractions, with total volatile yield (given high-temperature volatile yield) exceeding 1.7 times the results of standard technical analysis [6, 7].

Table 1

Temperature t (°C) of Wall Surface

No. area	t_{input}	$t_{average}$	t_{output}
1	1467	1467	1467
2	1242	1169	1063
3	1063	1038	964
4	964	929	908
5	908	850	781

The computation program describes the combustion of coal particles using *Non-Premixed Combustion* model and the volatile-matter yield by *Two Competing Rates* model. The irradiation is described by ***P-1*** model. The turbulence is taken into account using *Realizable k-epsilon* model with *Enhanced* function of the wall. The *Fluent* software enables to avoid direct setting of *epsilon* values at the inlet to estimated area using the *k-epsilon* turbulence model. The calculations have been made with setting the initial turbulence parameters (Tu = 10%) and hydraulic diameter.

The heat boundary conditions on the walls of estimated area were defined on the basis of the following assumptions. Surface temperatures av-

Table 2

Parameters of Inflows in Nominal Mode

Flow type	TCP burner				Standard burner			
	Air		Coal	Torsion	Air		Coal	Torsion
	*m** kg/s	*T* *K*	*m* kg/s	$(U_{tan.}/U_{ax.})$**	*m* kg/s	*T* K	*m* kg/s	$U_{tan.}/U_{ax.}$
Central flow	13.7	493	5.61	0.466	14.6	493	0	0.466
Primary air mix	18.1	387	11.22	1	18.1	387	16.83	1
Secondary air	114.6	493	0	1.73	114.6	493	0	1.73
Air for gas	0.87	323	0	0	0		0	0
Скидне повітря	12.6	387	0	0	12.6	387	0	0
Присмокти	7.80	313	0	0	7.80	313	0	0
Gas	0.24	323	0	0	0	0	0	0

Note. * *m* — consumption; ** $U_{танг.}/U_{ax.}$ — ratio of tangential to axial component of velocity.

Table 3

Technical Analysis of Anthracite

Content, wt.	V^r	$C(s)^r$	A^r	W^r
%	4	69	19,5	7,5

Table 4

Element Composition of Coal Organic As-Fired Fuel

Element composition	C^{daf}	H^{daf}	O^{daf}	N^{daf}	S^{daf}
%	92.5	1.97	2.58	0.79	2.14

erage weighted by surfaces of furnace zones (surface of slag layer) were taken from the results of zonal furnace computations for nominal load regime by standard method.

However, direct use of these data as boundary conditions is not fully correct, insofar as it means «non-physical» jumps of both surface temperature and heat flux densities at the boundaries of furnace zones.

Therefore, an option provided by ANSYS FLUENT software (which does not require any modification of grid model) was used for formulating heat boundary condition on the walls as heat resistance and temperature of the outer wall surface with respect to the estimated volume. The required parameters were taken from the mentioned zonal computations by standard method and from the thermal design documents for boiler furnace of Trypillia TES.

To solve the task, firstly, flows and nitrogen oxide formation processes were computed within the boiler volume that is approximately corresponds to contribution of one burner, instead of the whole furnace showed above. The method for separation of such volume is showed in Fig. 4 featuring the boiler furnace (top view).

The estimated area (as marked on the picture) sides with the 2nd (central) burner; the top and bottom symmetry planes are placed at a half of distances between the burner axes. The third symmetry plane is located at a half of distance between the fond and the rear surfaces of furnace.

These assumptions were made in order to reduce the volume of estimated area and, respectively, resource consumption and time for obtaining computation results. However, the results are explained by incomplete matching of model to the real object. In particular, the cross section of estimated area in this case is less than 1/6 cross section of the furnace (while the component consumption per a burner accounts for 1/6 of consumption for the whole furnace). Therefore, the time of particle stay within the estimated area in this model is underestimated. In addition, the share of wall surface in the estimated area perimeter is less than that in the real object. Finally, the direction of flow twist in the part of adjacent burners limiting the estimated area does not fully correspond to those in the real furnace, which affects gas fluxes in the burner neighborhood.

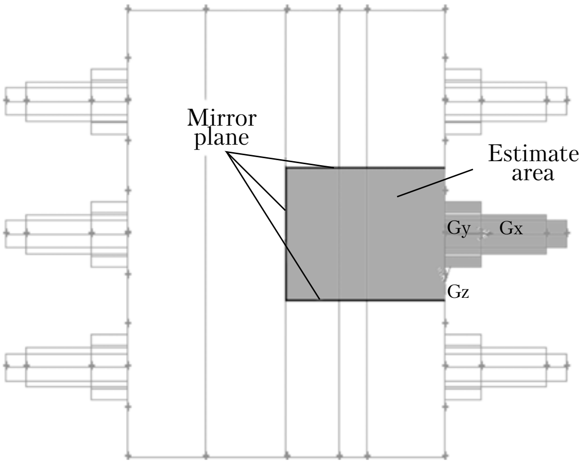

Fig. 4. Estimated area

RESULTS OF COMPUTATIONS

Firstly, the adequacy of obtained numerical model was assessed as compared with thermal design of boilers. Based on obtained results of simulation and computation by standard method (Fig. 5) one can conclude that, in general, they show a quite good qualitative and quantitative agreement. For the standard method being developed as generalization of long-term, primarily, in-situ surveys and trials of numerous operating boilers the obtained results of simulation can be considered satisfactory.

Further, the field parameters of boilers with TCP and standard burners were compared. Figs. 6—8 (see color inset) show the obtained temperature distributions for gaseous phase in various cross sections of the furnace. In both cases the temperature fields are similar. Local temperature maximum (Fig. 6) is lower for the TCP burners, which can favorably affect the formation of nitrogen oxides. The maximum temperature zones in both cases correspond to heat insu-

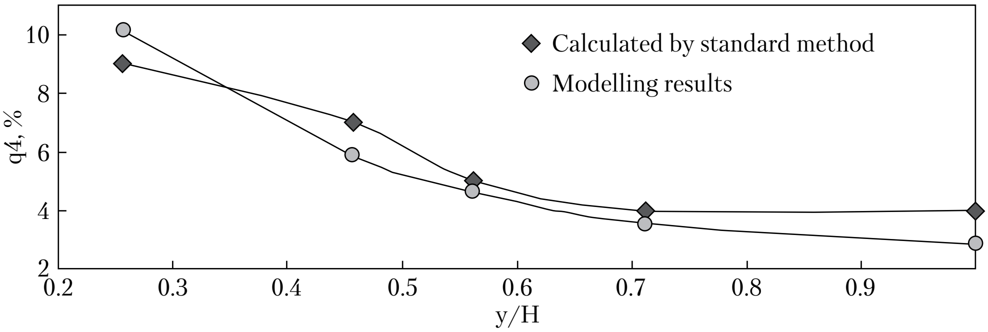

Fig. 5. Comparison of dependence of the share of unburnt fuel along the furnace vertical for the simulation results and the thermal design, by standard method

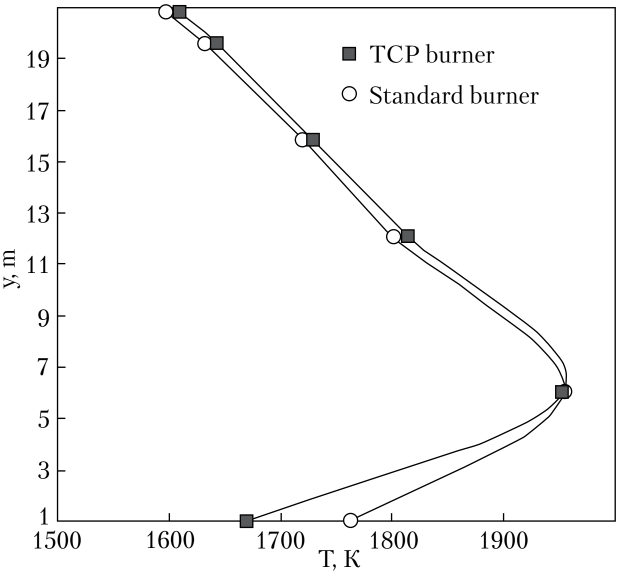

Fig. 9. Average temperature along the furnace vertical

lated lower radiant section (LRS); thereafter, temperature falls sharply as a result of intensive radiation exchange.

At the level of neck, the average temperature of cross section (Fig. 9) is higher for the case of TCP burners, as compared with the standard ones (1934 and 1916 K, respectively). Vertically up, the gaseous phase gets cooler almost with a linear pace in both cases. A difference of approximately 20 K remains fixed until the end of estimated area, where the average temperatures are 1593 and 1576 K for the TCP and the standard burners, respectively.

Fig. 8 features a temperature field of LRS wall surfaces (including the furnace bottom), which is the most interesting. The TPP-210A boiler having liquid slag to be removed, temperature near the slag tap opening significantly influences the reliability of boiler operation. Temperatures near the slag tap opening do not differ essentially, i.e. despite lower core temperature for the TCP burners the discharge of liquid slag is not impaired.

Oxygen concentration fields (Fig. 10, see color inset) are similar for both cases, in general. At the exit from the estimated area the volume oxygen concentration is almost the same in both cases (2.53 and 2.52% for the TCP and the standard burners, respectively). However, since pyrolysis and combustion in the case of TCP burners start as early as in the muffle, oxygen concentration in the furnace is less along the vertical as compared with the standard burners. In the case of TCP burners, in the active combustion zone, there are areas where oxygen concentration is almost zero. This creates a reducing environment where reaction of nitrogen reduction from its oxides can take place, which should stimulate a decrease in the total and output concentration of nitrogen oxides.

At the same time, a decrease in oxygen concentration impairs the combustion process (Fig. 11), which can lead to a certain increase in concentration of combustibles in the discharged gases for the TCP burners as compared with the standard ones. Therefore, in the future, the TCP method is planned to be used in combination with in-fur-

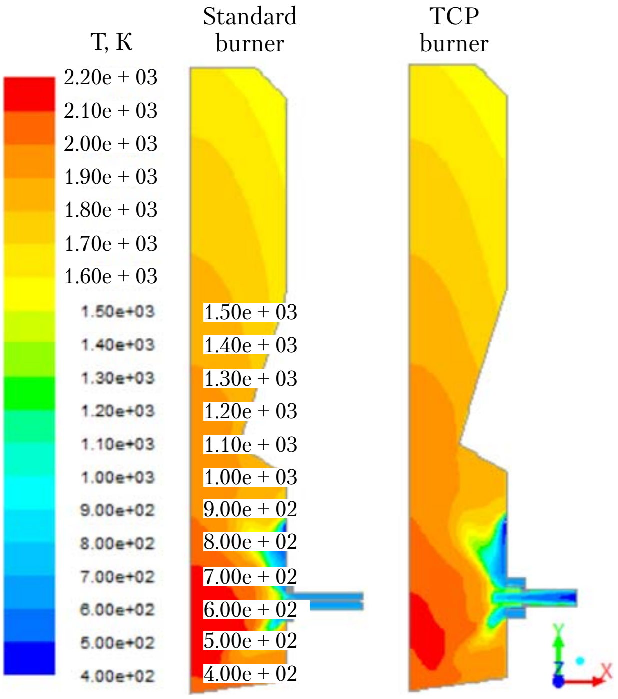

Fig. 6. Temperature field for different burners in X—Y plane

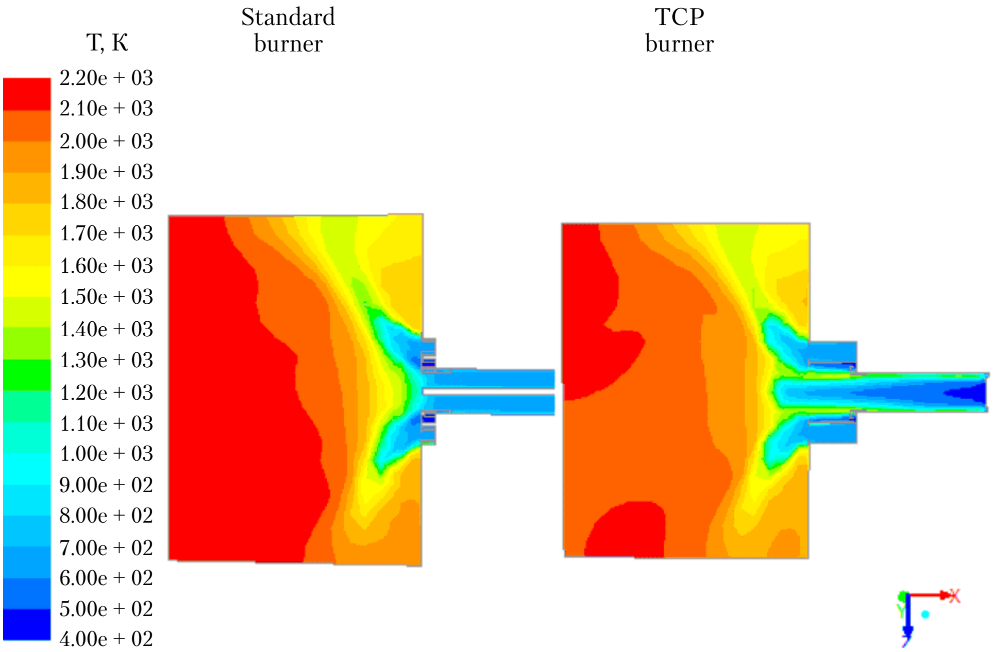

Fig. 7. Temperature field for different burners in Z—X plane at the level of burners

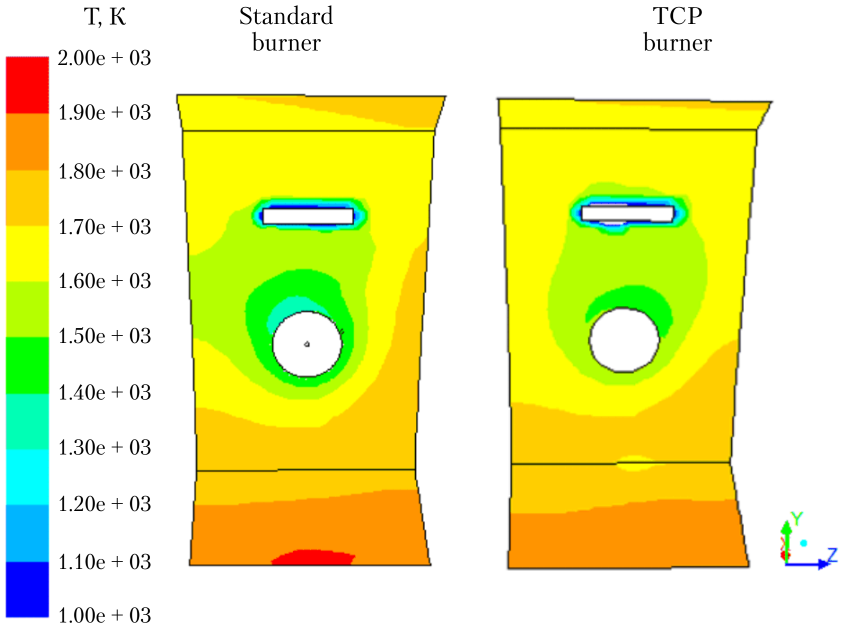

Fig. 8. Temperature field for different burners on LRS wall surface

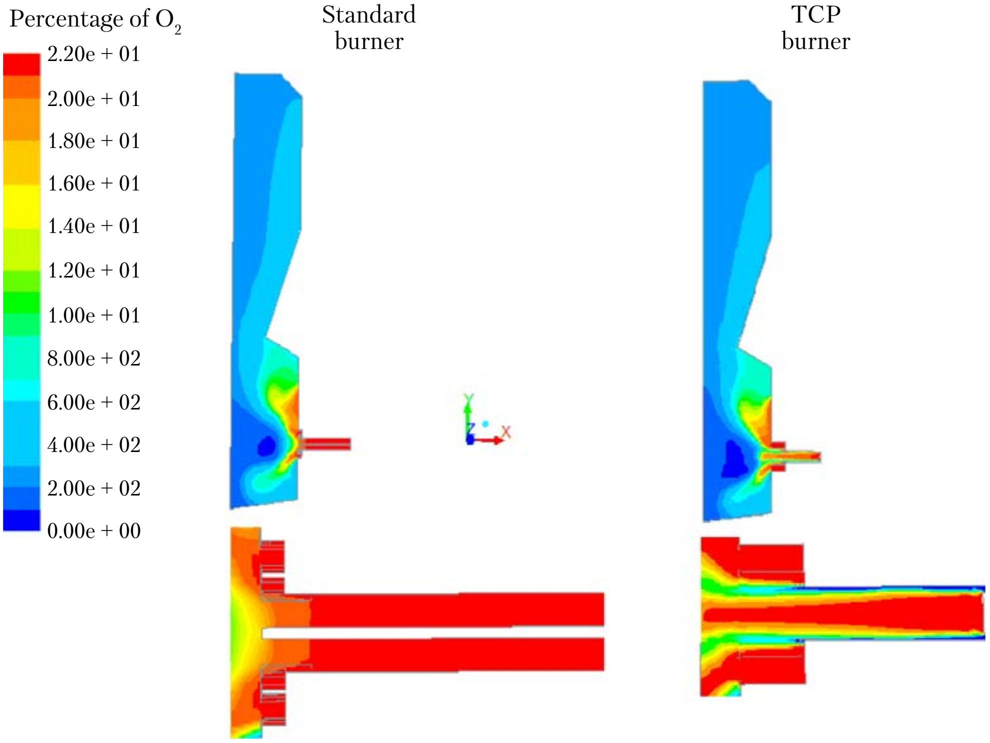

Fig. 10. Oxygen concentration fields for different burners in *X*—*Y* plane. Below, the enlarged burner areas are showed

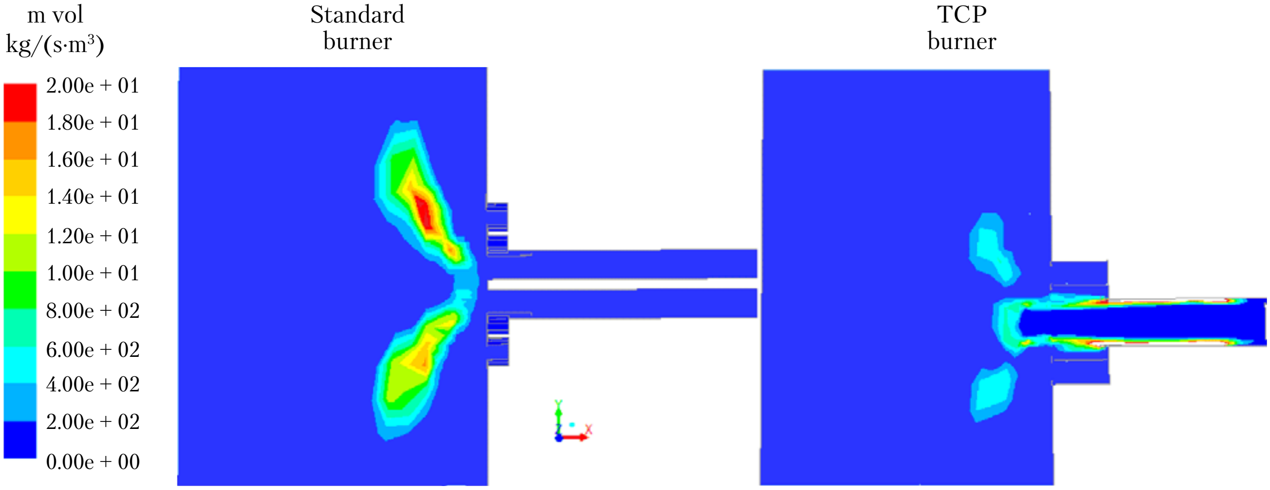

Fig. 12. Devolatilization intensity field for different burners in *X*—*Y* plane

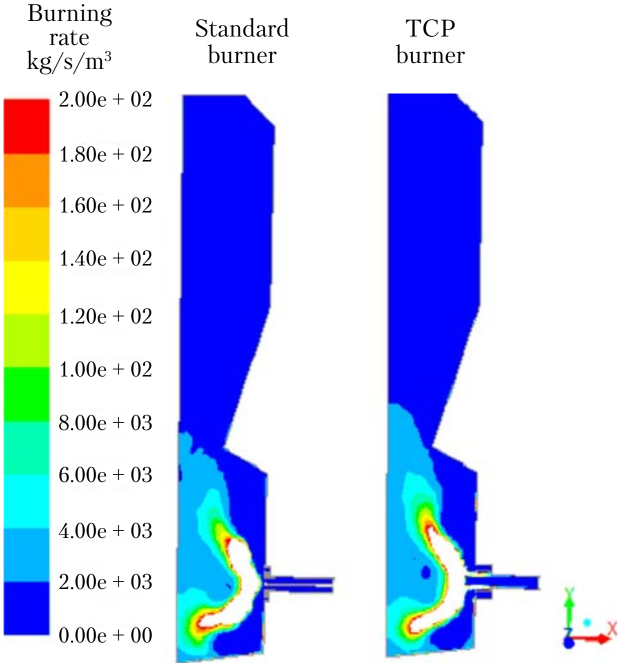

Fig. 13. Coke residual combustion rate field for different burners in *X*—*Y* plane

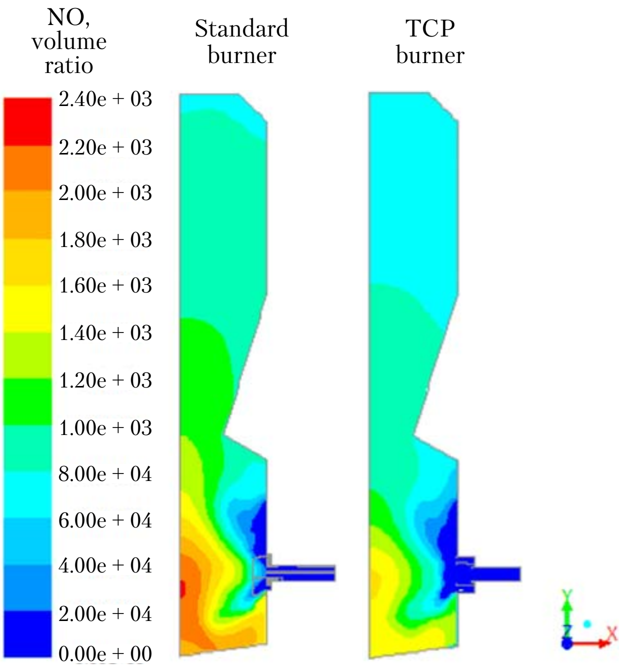

Fig. 15. Nitrogen oxide concentration field for different burners in *X*—*Y* plane

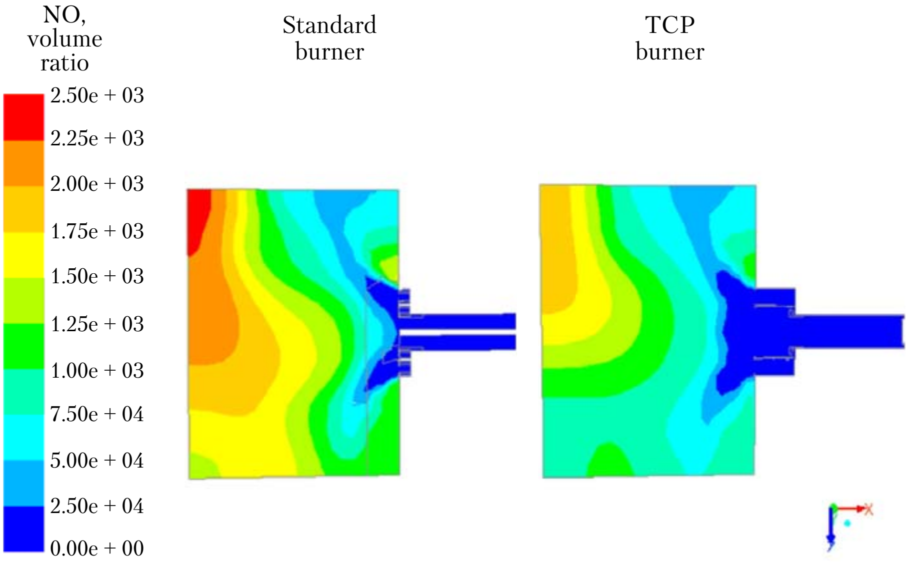

Fig. 16. Nitrogen oxide concentration field for different burners in Z—X plane at the level of burners

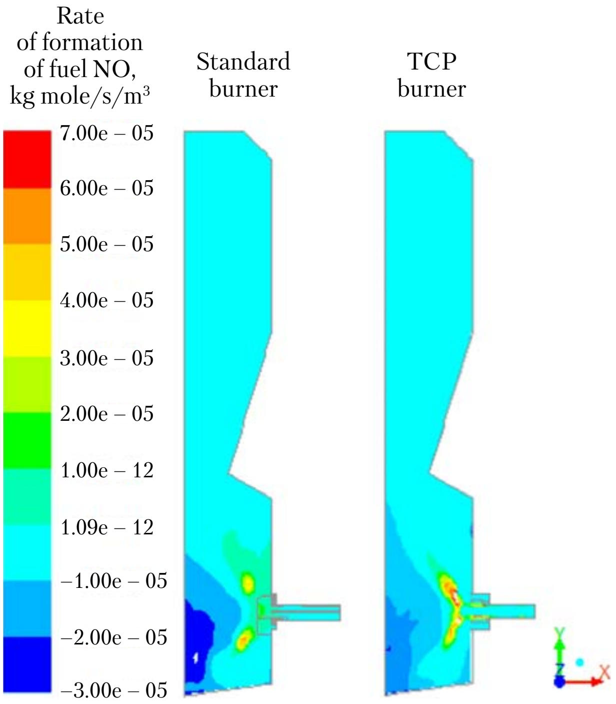

Fig. 17. Rate of formation of fuel nitrogen oxides along the furnace vertical

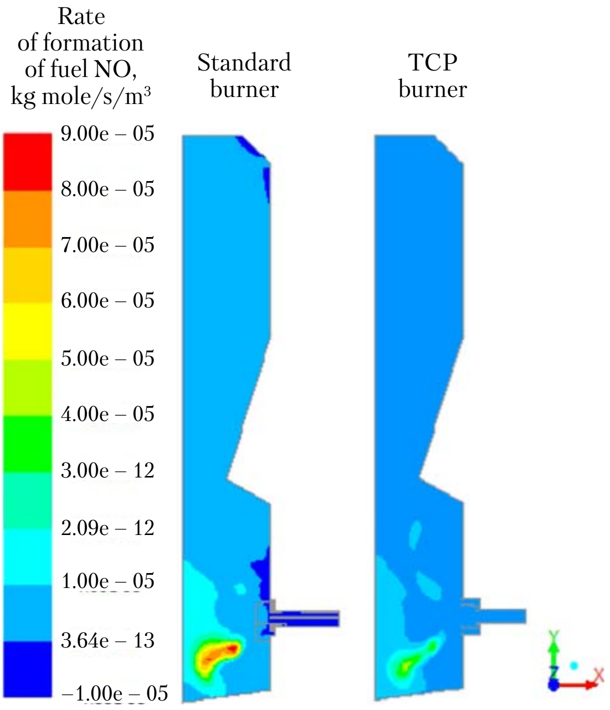

Fig. 18. Rate of formation of thermal nitrogen oxides along the furnace vertical

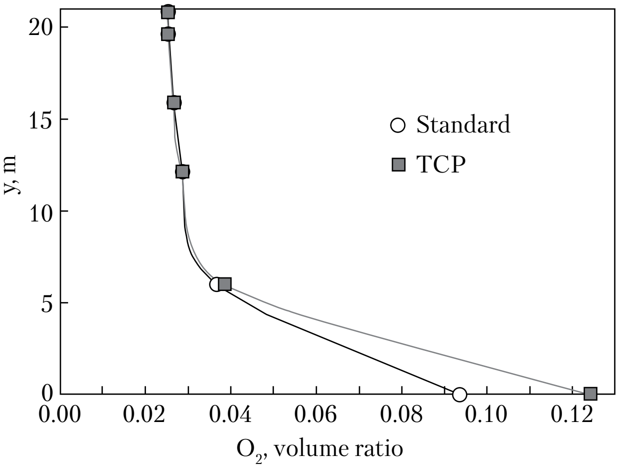

Fig. 11. Average oxygen concentration along the furnace vertical

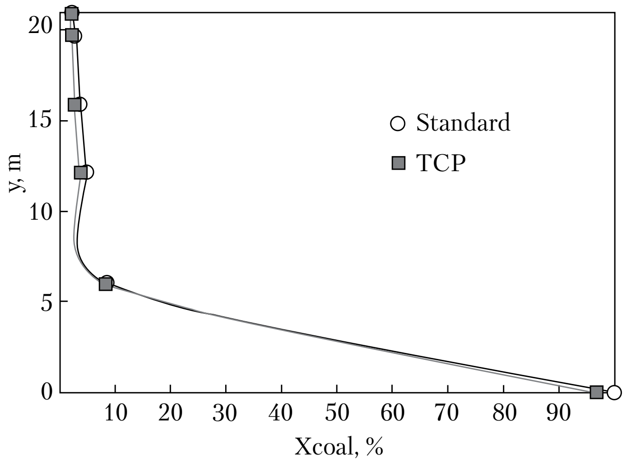

Fig. 14. The share of unburnt coal along the furnace vertical

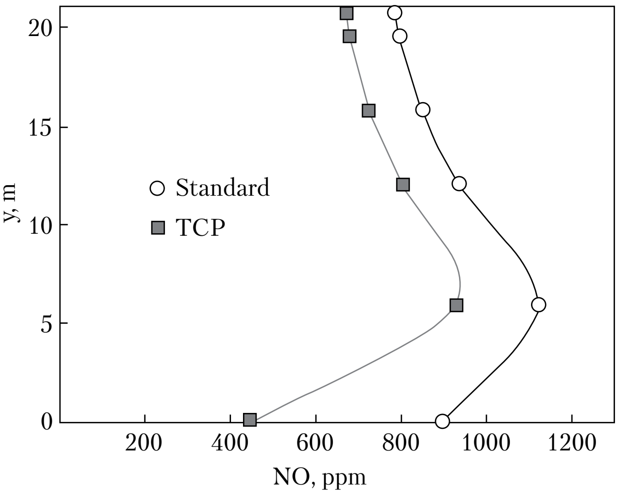

Fig. 19. Average nitrogen oxide concentraion along the furnace vertical

nace measures for raising efficiency and environment compatibility of combustion.

Volatile yield fields show the key effect of TCP method on the air mix as devolatilization and combustion of a part of volatile matter occur inside the burner, which makes the ignition of low-volatile coal more reliable. Fig. 12 (see color inset) show that in the case of TCP, the devolatilization ends earlier that in the case of use of standard burners. In both cases, devolatilization ends (rate falls under $5{\cdot}10^{-3}$ kg/(s·m^3)) within distance of the 1st gage from the burner cut. Having compared the data of Fig. 12 with those of Fig. 10, one can see that in the case of TCP burner the most intensive devolatilization is localized within areas with insufficient amount of oxygen. This stimulates a decrease in the intensity of nitrogen oxide formation in such burner.

Combustion of coke residue lasts as long as coal particles stay in the furnace (Figs. 13 (see color inset), 14). In the case of TCP burner, the combustion starts inside the burner and is more intensive near the burner. Further, the solid particle combustion rate becomes even along the furnace vertical (Fig. 14). The share of incompletely burnt coal particles at the exit is 2.09 and 2.87% for the TCP and the standard burners, respectively, which means that early ignition has a more important effect on complete combustion than reduced oxygen concentration. The share of unburnt matter is defined by the formula:

$$X_{coal} = (B_{cr}^{in} + B_{vol}^{in} - (B_{cr}^{out} + B_{vol}^{out}))/(B_{cr}^{in} + B_{vol}^{in}) \times 100, \qquad (1)$$

where B_{cr}^{in} and B_{cr}^{out} — consumption of combustible part of coke residual at the input and the output, respectively; B_{vol}^{in} and B_{vol}^{out} — consumption of volatile matter at the input and the output, respectively.

Earlier start of coal combustion in the case of TCP burners enables to ensure more effective burn-off, and, consequently, to save fuel.

When computing the nitrogen oxide formation all three mechanisms were taken into account: the *thermal*, the *fuel*, and the *rapid* ones [8]. In the furnace neck and at the output, lower concentrations of nitrogen oxides were obtained in the case of configuration with TCP burners. The computed NO concentration fields (Figs. 15—16, see color inset) confirm the assumption that the main difference in nitrogen oxide formation resulting from the use of TCP method is in the lower part of LRS where active combustion of coal takes place. In the case of TCP burners that have lower temperature of flame core and lower concentration of oxygen in this region of LRS, lower yield of thermal nitrogen oxides is reported. This has been confirmed by the fields of rates of formation of fuel and thermal nitrogen oxides (Figs. 17 and 18, respectively, see color inset). Further, the combustion conditions become even along the furnace vertical, with the diagrams of average NO concentrations being almost equidistant (Fig. 19). Nitrogen oxide concentration is lower by 10—15% in the case of TCP burners.

CONCLUSION

A computational analysis of operation of furnace equipped with standard burners and with TCP burners has showed the following:

1. For the use of standard burners of TPP-210A boiler temperature and level of burn-off in the furnace have been computed for 100% load using ANSYS FLUENT program. The results are in good agreement with the thermal design of boiler specifications;

2. The TCP method enables improving ignition conditions at the output from burners and raising the share of burnt coal particles in the furnace.

3. The use of TCP burners enables to decrease nitrogen oxide concentration at the exit from the furnace by 10—15%.

4. To reach the European standards for nitrogen oxide emission of flame boilers, in addition to the use of TCP burners, other in-furnace measures shall be taken (staged combustion, chemical NOx absorption methods, etc.).

5. The computation results are deemed rough estimates as a result of assumptions made for simplification and speedup of computations. Subsequent computations (in particular, for the full size furnace) and the results of full scale tests will define the data more exactly.

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ТЕХНОЛОГІЯ ЗНИЖЕННЯ ВИКИДІВ ОКСИДІВ АЗОТУ ПРИ ФАКЕЛЬНОМУ СПАЛЮВАННІ ВУГІЛЛЯ

Для оцінки ефективності впливу термохімічної підготовки антрациту на утворення оксидів азоту була створена тривимірна числова модель частини паливні котла ТПП-210А для стандартних і модифікованих пальників. Результати розрахунків показали зниження концентрації оксидів азоту по всій висоті паливні при зменшенні ступеню недопалювання вугілля для модифікованих пальників у порівнянні зі стандартними пальниками.

Ключові слова: оксиди азоту, антрацит, пальник, вугілля, термохімічна підготовка.

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ТЕХНОЛОГИЯ СНИЖЕНИЯ ВЫБРОСОВ ОКСИДОВ АЗОТА ПРИ ФАКЕЛЬНОМ СЖИГАНИИ УГЛЯ

Для оценки эффективности влияния термохимической подготовки антрацита на образование окислов азота была создана трехмерная числовая модель части топки котла ТПП-210А для стандартных и модифицированных горелок. Результаты расчетов показали снижение концентрации окислов азота по всей высоте топки при уменьшении степени недожога угля для модифицированных горелок по сравнению со стандартными горелками.

Ключевые слова: оксиды азота, антрацит, горелка, уголь, термохимическая подготовка.

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