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STUDY OF THE INFLUENCE OF VARIOUS METHODS OF FUEL INPUT THROUGH BURNERS ON COMBUSTION PROCESSES

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Abstract. *This paper presents new results of computational experiments to study the influence of various methods of fuel input (straight flow and vortex with a flow deflection angle of the pulverized coal stream) across the firing systems on combustion processes utilizing the BKZ-75 boiler combustion chamber case of the Shakhtinskaya TPP (Kazakhstan), fluidized combusting Karaganda coal with high ash content. According to the results of computational combustion modeling, the following results were derived: the total velocity vector distributions, spatial distributions of temperature, and concentrations of carbon oxides and nitrogen dioxide (NO_2) within the full volume through the combustion zone and at the chamber's discharge. It has been appeared that the vortex strategy of providing the discuss blend makes it conceivable to enhance the method in the combustion of high-ash coal, as in this case there's an increment in temperature within the center of the burn and a lower temperature observed at the combustion zone outlet, which features a noteworthy effect on the chemical forms of the arrangement of reaction products formed during combustion. When employing vortex burner devices, the concentration levels at the combustion outlet zone for carbon monoxide (CO) decrease by about 15 %, and for nitrogen dioxide (NO_2) by roughly 20 % relative to direct-flow burner devices. The comes about gotten make it conceivable to create proposals for the advancement of ideal strategies for managing flame structure and combustion dynamics of a pulverized coal burn to extend the productivity of vitality offices and decrease emanations of hurtful substances into the environment.*

Keywords: combustion, simulation, coal-fired power plant, linear-flow and swirling-flow burners, thermal field, carbon monoxide emission, toxic nitrogen compounds.

1. Introduction

Today, energy consumption is the largest source of anthropogenic greenhouse gas emissions, contributing to global warming [1]. According to the International Energy Agency (IEA) for 2022, the world's most significant sources of energy are petroleum, coal, and natural gas (Figure 1) [2]. Just over 16% of global energy comes from low-carbon sources, of which approximately 11% comes from renewable fuels and renewable municipal waste (biofuels and biomass). The remaining clean energy sources include hydropower, geothermal energy, solar energy, wind energy, tidal energy, and wave energy.

The global community is rapidly moving to achieve complete decarbonization of the global economy by 2050, introduce a carbon tax, and strengthen adaptation measures to the impacts of climate change. The Paris Agreement on climate change ignited the carbon neutrality movement, with the European Union, the United Kingdom, Japan, Korea, and more than 110 other countries committing to carbon neutrality by 2050. However, carbon dioxide emissions are still at record levels and are rising rapidly [2].

Despite the growing popularity of alternative sources, electric coal remains the primary method for producing electricity. The IEA indicated that high coal demand will remain stable until 2025. Although Western countries want to reduce coal consumption, it will continue in Asian markets. The world is close to peak fossil fuel use, and coal will be the first to decline, but the world is not there yet. Request for coal waste resolved and is expected to hit record-breaking level this year, expanding worldwide emanations [2].

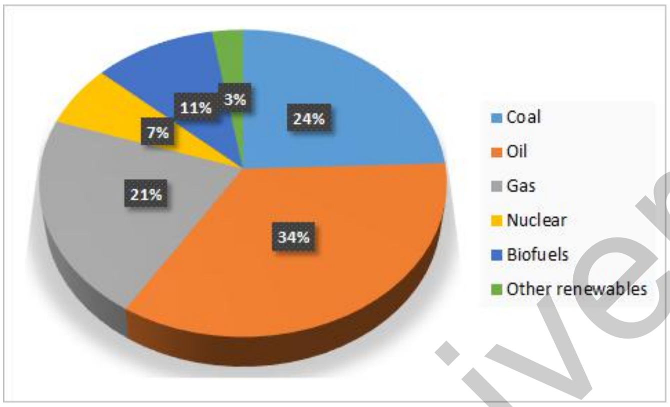


Fig.1. Fuels' share of the world's total primary supply in 2025 [2].

The coal industry faces a paradoxical situation. While the global green transition frames coal as the dirtiest source of electricity, it continues to serve as an affordable and dependable resource with rising demand. Indeed, although driving countries have announced approach to realize carbon nonpartisanship over period 2020-2060, coal generation is impossible to decrease before long. Fueled by tall common gas costs, rising power request, and fast mechanical and vitality division development in India, China, and Southeast Asia, coal is anticipated to preserve its current proportion within the vitality blend for at slightest other 5-10 a long time [3–6].

According to the International Energy Agency (IEA), global coal consumption will likely rise in the coming years. The post-COVID recovery has driven energy demand sharply upward, prompting a resurgence of coal use. In the EU, previously retired coal-fired power plants are being reactivated, while in the United States, coal mining is experiencing its first revival in a decade. This “coal resurgence” started in 2021 in the midst of the vitality emergency, as clean energy demonstrated fewer solid, compelled by both characteristic situations (moo wind and cold climate) and by technological challenges (including the surge in solar panel production). As a result, coal has returned to the global energy mix despite strong opposition from environmentalists [2].

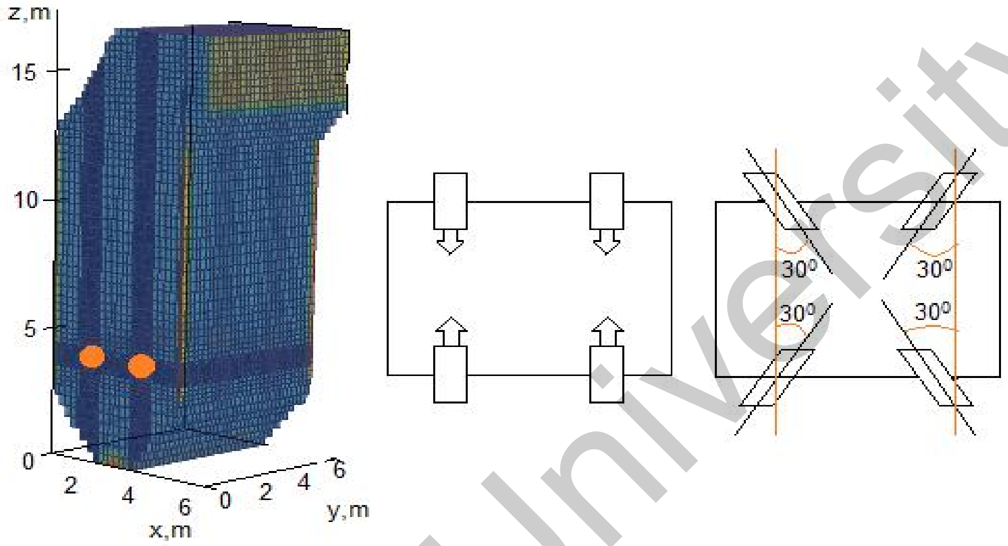
Coal-based power generation continues to play a crucial role in the economies of many countries and in ensuring public welfare [7–11]. In response to global environmental priorities, the industry is working to develop “clean” coal utilization and processing technologies while meeting strict ecological standards. This makes research on combustion processes in power plant chambers and identifying optimal fuel-burning methods especially relevant. Although the share of coal-fired plants is expected to decline, coal will remain the primary fuel for Kazakhstan’s thermal power sector. Subsequently, a key challenge for household control designing is planning and executing ecologically inviting advances at coal-burning facilities in Kazakhstan control that direct toxin arrangement forms and reduce outflows [12-17].

This study presents computational experiments to analyze the influence of different fuel injection methods-direct-flow and vortex, with a specified swirl angle of the pulverized coal stream through burner devices on combustion processes. Environmentally optimal air supply configurations for the combustion chamber were identified. Cutting-edge numerical devices empowered detailed 3D representations of the results, which had been confirmed against test data obtained from a working warm control station [18-21].

2. Materials and methods

Structural and Functional Description of the Combustion Chamber

To implement numerical simulation techniques, we chose the combustion zone of the BKZ-75 steam-generating unit, introduced at the Shakhtinskaya TPP located in Kazakhstan, in which Karaganda coal with ash content 35.1 % is combusted. The object of study is the BKZ-75 vertical water-tube steam boiler, operating at a capacity of 75 t/h (51.45 GCal/h). Figure 2a illustrates a boiler schematic and a finite difference framework used for running computational tests.



a) b) c)

Fig. 2 Evaporator graph and finite-difference framework (a) and diverse plans of burner gadgets course of action: direct-flow (b) and vortex (c) within the firebox of the BKZ-75 evaporator

The evaporator utilizes four burners for pulverized coal combustion, two introduced at the front side and raised to one level. Figure 2a shows a pot chart and a finite-difference approach for executing computational tests. Below are the comes about of computational tests to think about warm forms, streamlined and analysis of concentration profiles in the combustion zone of the BKZ-75 boiler at the Shakhtinskaya Thermal Power Plant [12-14, 17] for the shown two modes of providing coal powder fuel: 1) direct-flow approach of providing the discuss blend burners are found on inverse side dividers (Figure 4b); 2) vortex approach of providing the discuss blend - burners with a whirl point of the discuss blend stream and a 30-degree tilt toward the boiler's central symmetry (Figure 2c) [22-24].

The initial data for carrying out numerical modeling and numerical experiments on fuel combustion in the combustion chamber of the BKZ-75 boiler, as well as all the necessary parameters of coal dust are presented in Tables 1-2.

Table 1. Composition and initial data of Karaganda coal

Composition of the original coal dust, %		Initial data of Karaganda coal			
		Name of the parameter	Designation	Unit of measurement	Meaning
W	10,60	Type of coal	KR-200	-	-
A	35,10	Fineness of grinding	R_{90}	%	20
S_2	1,04	Density of coal	ρ	kg/m^3	1300
C	43,21				
H_2	3,60				
O_2	5,24	Heat of combustion of coal	Q_L^R	kcal/kg	4433
N_2	1,21				
V	22,00				

Table 2. Calculated performance indicators of the combustion chamber of the BKZ-75 boiler

№	Parameter name	Designation	Unit of measurement	Meaning
1	Nominal steam capacity	D	t/h	75
2	Boiler efficiency	η	%	80.88
3	Height of the combustion chamber	h(z)	m	16.75
4	Firebox width	x	m	6
5	Depth of the combustion chamber	y	m	6.6
6	Number of burners on the boiler	N	pcs.	4
7	Fuel efficiency of one burner	B	t/h	3.2
8	Primary air flow rate to the boiler	V_p	nm^3/t	31797
9	Secondary air consumption for the boiler	V_s	nm^3/t	46459
10	Excess air coefficient in the furnace	α		1.2
11	Hot air temperature	t_h	°C	290
12	Suction cups in the firebox	$\Delta\alpha_t$	-	0.10
13	Estimated fuel consumption for the boiler	B	t/h	12.49
14	Cold air temperature	t_c	°C	30
15	Air mixture temperature	t_{air}	°C	140
16	Wall temperature	t_w	°C	430.15

3. Results

Underneath are the results of a consideration of warm forms, streamlined, and concentration fields in the BKZ-75 boiler combustion chamber at the Shakhtinskaya TPP for two coal feed modes.

3.1. Investigation of the airflow dynamics within the firebox of the BKZ-75 boiler

Figures 3–4 show the optimal design of the firebox of the BKZ-75, specifically the conveyance of the complete velocity vector $v=\sqrt{U^2+V^2+W^2}$ across its different sections. The complete velocity vector is displayed within the figures underneath in the shape of bolts of distinctive colors. The heading of the arrow indicates the course of the medium's speed, and utilizing the color scale, you'll decide its numeric value. The coming about areas of the overall velocity vector empower the investigation of the development of responding streams within the combustion space, as appeared in its different areas, as demonstrated within the illustrations.

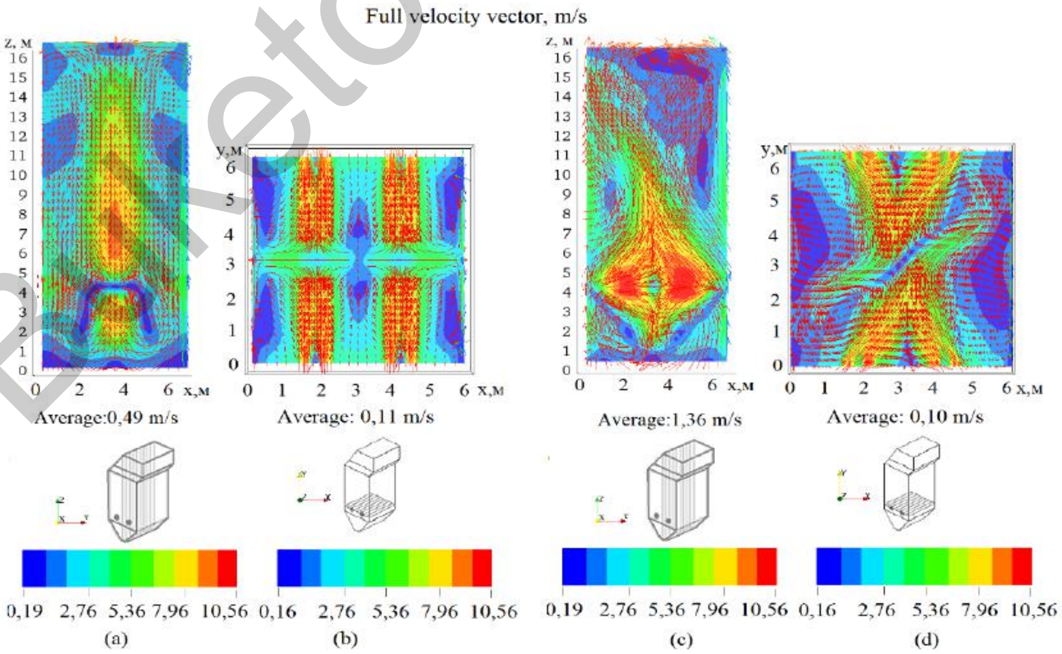


Fig. 3. Conveyance of the entire velocity within the longitudinal (x=3.0 m) and transverse areas of the firebox (burner zone, h=4.0 m) of the BKZ-75 with: direct-flow (a, b), vortex approach of discuss blend supply (c, d)

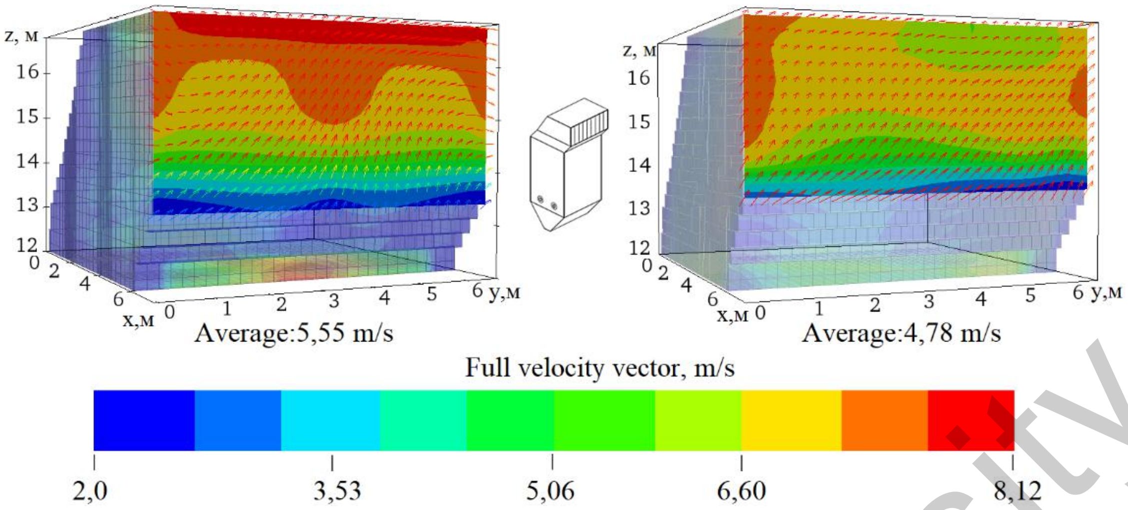


Fig. 4. Conveyance of the entire velocity in cross segments at the outlet (h=16.75 m) from the firebox BKZ-75 with: a) direct-flow and b) vortex approach of providing the discuss blend.

Figure 3 outlines the conveyance of the overall speed vector within the longitudinal (x = 3.0 m) and transverse (h = 4.0 m, burner zone) segments of the firebox BKZ-75 for direct-flow (Fig. 3a, b) and vortex (Fig. 3c, d) air supply approaches. Within the direct-flow setup, planes from restricting burners impact at a right point within the chamber center, part into littler rivulets, and blend into two prevailing streams coordinated for the pipe (Fig. 3a, b).

In contrast, the vortex method generates a markedly different flow structure. Air–fuel jets introduced at a 30° swirl angle create a central vortex within the chamber (Fig. 3c, d). Four swirling streams converge at the chamber center, interact at a 30° angle, and merge into a stronger, unified vortex directed toward the outlet. Comparison of the two modes reveals that the vortex method enhances turbulence, leading to intensified mixing. Incomplete combustion of coal particles is a well-known issue. Some particles are entrained by flue gases as fly ash, while others are removed with slag via the cold funnel, resulting in mechanical heat losses. Examination of the velocity (Fig. 3) shows that the vortex strategy advances more overwhelming circulation of dust gas streams, expanding coal grain residence time in the combustion zone. This reduces the extent of mechanical under burning and contributes to more complete fuel utilization in the BKZ-75 boiler.

Figure 4 presents the velocity distribution in transverse sections at the chamber outlet (h = 16.75 m). As the planes are absent from the burner zone, velocity vectors steadily equalize, the vortex is debilitated, and the stream grows to attain a uniform conveyance over the exhaust cross-section. Notably, the mean outlet velocity for the vortex case (4.78 m/s) is lower than for the direct-flow case (5.55 m/s), suggesting improved energy dissipation and flow uniformity under vortex combustion conditions.

3.2 Investigation of the thermal properties of the combustion chamber

Utilizing computational analysis, temperature areas were gotten in several segments of the firebox BKZ-75 for two discuss supply modes: coordinate stream and vortex (Fig. 5). The 3D plots with temperature scales allow determination of local values throughout the chamber. A clear qualitative difference is observed between the two cases. Quantitatively, the average temperature at the burner level (h = 4.0 m) is 620 °C for the direct-flow method and 854 °C for vortex burners. In both modes, most extreme temperatures happen close the firebox; be that as it may, for direct-flow burners, high-temperature zones move toward the dividers, expanding their warm stack (Fig. 5b). Within the case of vortex burners with a 30° whirl point, the flame core is concentrated within the central part of the firebox (Fig. 5c, d), bringing down the walls' warm stack. This impact emerges from the stronger vortex stream, improving convective warm exchange and expanding the residence time of coal elements within the combustion region.

This slant is affirmed by three-axis (Fig. 6a) and two-axis (Fig. 6b) temperature disseminations along the chamber stature for both air supply modes. The average temperature profiles (Fig. 6a) demonstrate that the vortex method extends the high-temperature zone. The minima observed in the curves (Fig. 6b) corresponds to the burner level (h = 4.0 m), where the entering air mixture has a lower temperature.

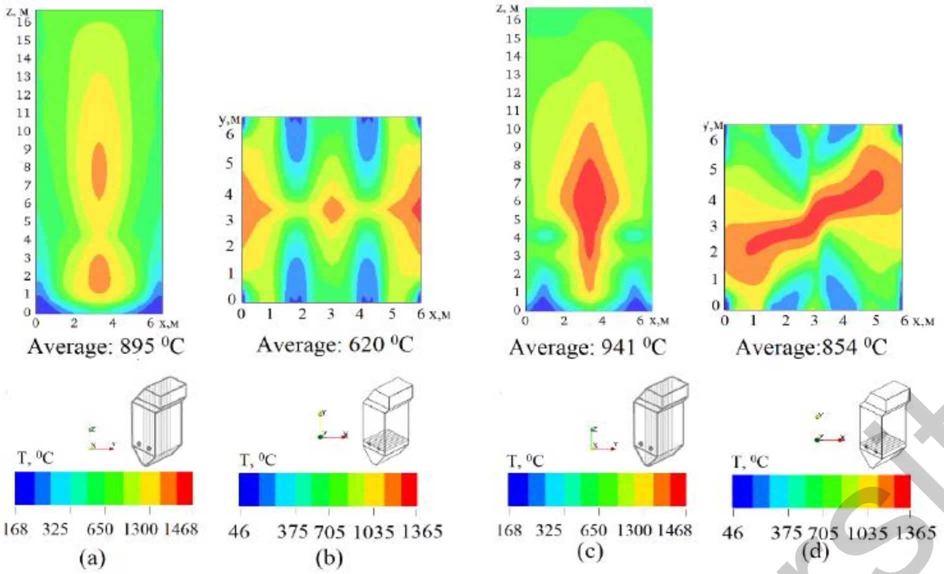


Fig. 5. Temperature dissemination within the longitudinal (x=3.0 m) and cross areas of the firebox (burner region, h=4.0 m) of the BKZ-75 with: direct-flow (a, b) vortex approach of providing the discuss blend (c, d).

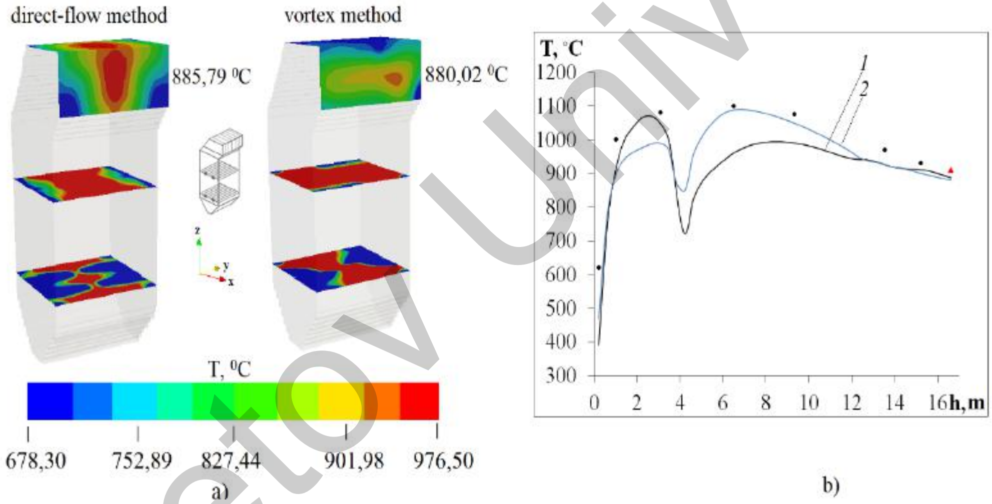


Fig. 6. Three-dimensional a) and two-dimensional b) dispersions of temperature T along the stature of the firebox h of the BKZ-75 kettle with: bend 1 direct-flow and bend 2 vortex strategy of providing the discuss blend;
● exploratory values [25]; ▲ hypothetical esteem gotten utilizing the CBTI strategy [17].

At the chamber outlet, the mean temperature is 886 °C for the direct-flow configuration (Fig. 6a, b, curve 1) and 880 °C for the vortex case (Fig. 6a, b, curve 2). Experimental data [25] plotted on the graphs confirm close agreement between simulation and full-scale measurements. Moreover, the outlet temperature for the direct-flow mode is consistent with the theoretical value as predicted by the Central Boiler and Turbine Institute (CBTI) methodology [17], further validating the numerical results.

3.3 Consider the concentration areas of combustion items of pulverized coal fuel in the firebox.

Switching from direct-flow to vortex fuel stock, with jets slanted 30° toward the chamber pivot and conferring a twirl to the air fuel blend, modifies the temperature conveyance inside the firebox and subsequently affects the concentration fields of combustion products. Specifically, extreme temperatures within the fire center and lower amounts at the outlet strongly influence the chemical pathways of product formation [21]. Figures 7-8 present computational results for carbon monoxide (CO) concentration fields in various sections of the BKZ-75 boiler under both air supply modes. Figure 7 shows the CO distribution in longitudinal (x = 3.0 m) and transverse sections at the burner level (h = 4.0 m), comparing direct-flow (a, b) and vortex (c, d) operation. In both cases, maximum CO concentrations are localized near the chamber center, corresponding to the burner region. This zone, where contradicting fuel discusses planes cross, shows strong burning and hoisted temperatures (~1400°C). Beneath these situations, fragmented fossil fuel oxidation happens, and carbon monoxide is effectively formed through chemical reactions between the ground coal and the oxidizing medium. Thus, the air supply method not only modifies flow and temperature fields but also governs the spatial distribution and intensity of CO formation within the burning area.

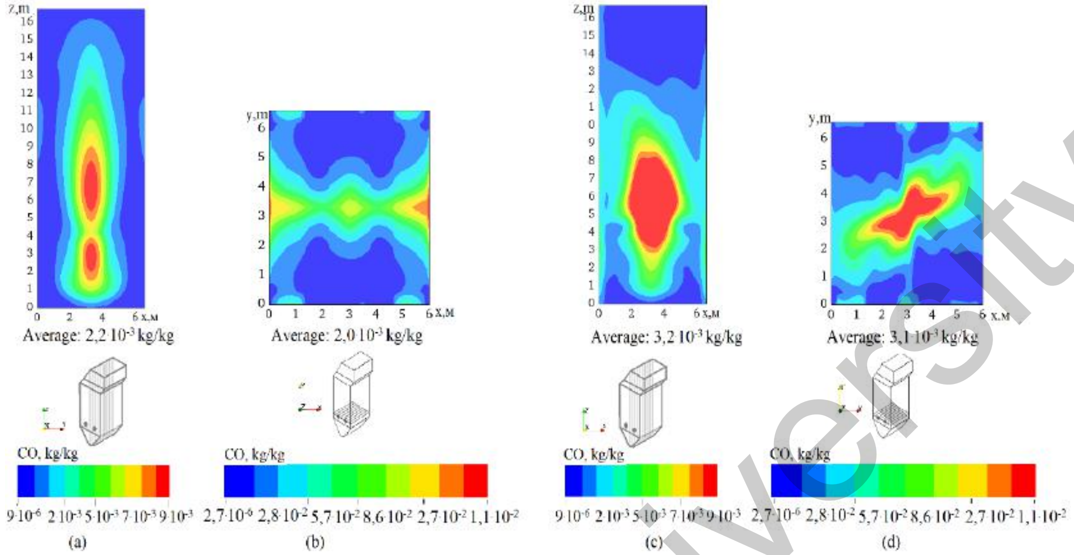


Fig. 7 Dispersion of the concentration of carbon monoxide CO within the longitudinal (x=3.0 m) and cross areas of the firebox (burner range, h=4.0 m) of the BKZ-75 evaporator with: direct-flow (a, b) and vortex strategy of providing the discuss blend (c, d).

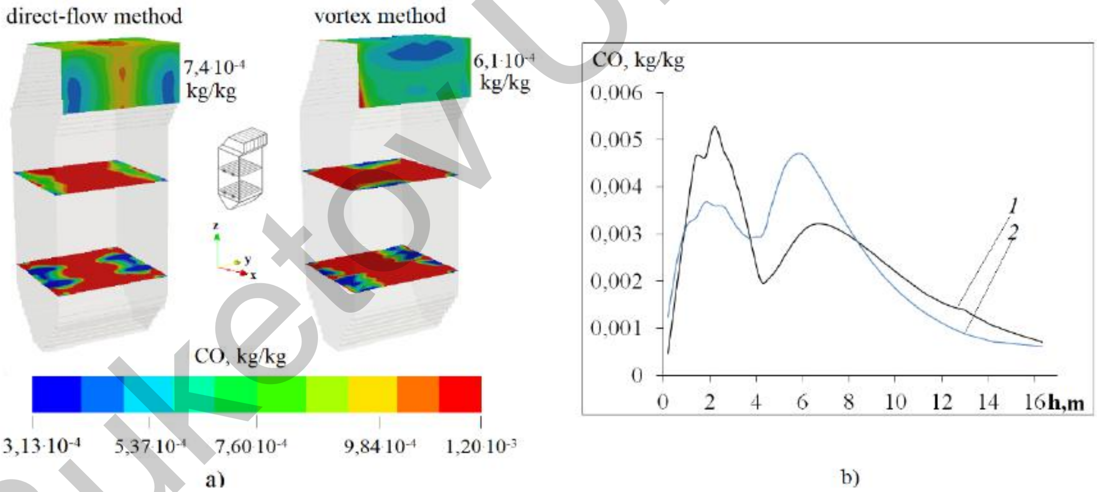
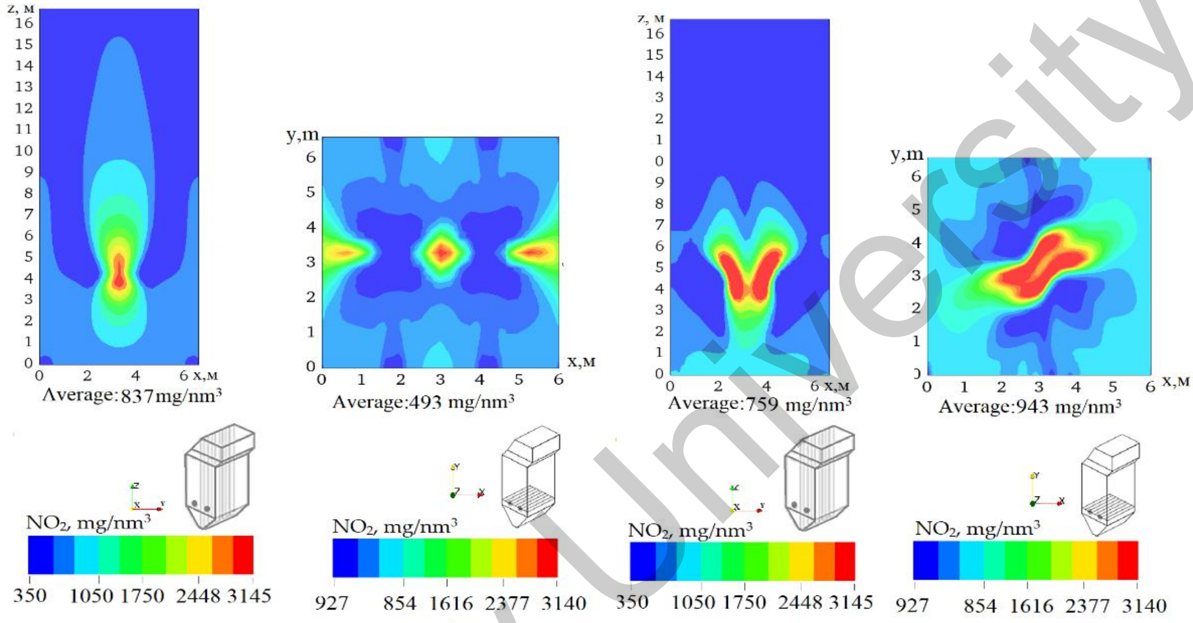


Fig. 8. Three-dimensional a) and two-dimensional b) conveyances of concentrations of carbon monoxide CO along the tallness of the combustion chamber h of the BKZ-75 evaporator with: bend 1 - direct-flow and bend 2 - vortex strategy of providing the discuss blend.

Analysis of Figure 8 shows that beneath the vortex, the supply form of carbon monoxide (CO) concentrations is elevated within the central locale of the firebox, especially within the flame region, associated to the direct-flow approach. This increment is ascribed to higher temperatures, forcing combustion responses, and increasing total carbon transformation. At the same time, the higher combustion intensity accelerates the subsequent oxidation of CO to carbon dioxide (CO_2). As a result, CO concentrations are lower at the chamber outlet using the vortex method. This trend is confirmed by the three-dimensional (Fig. 8a) and two-dimensional (Fig. 8b) disseminations of normal CO concentration along the space tallness for both working ways.

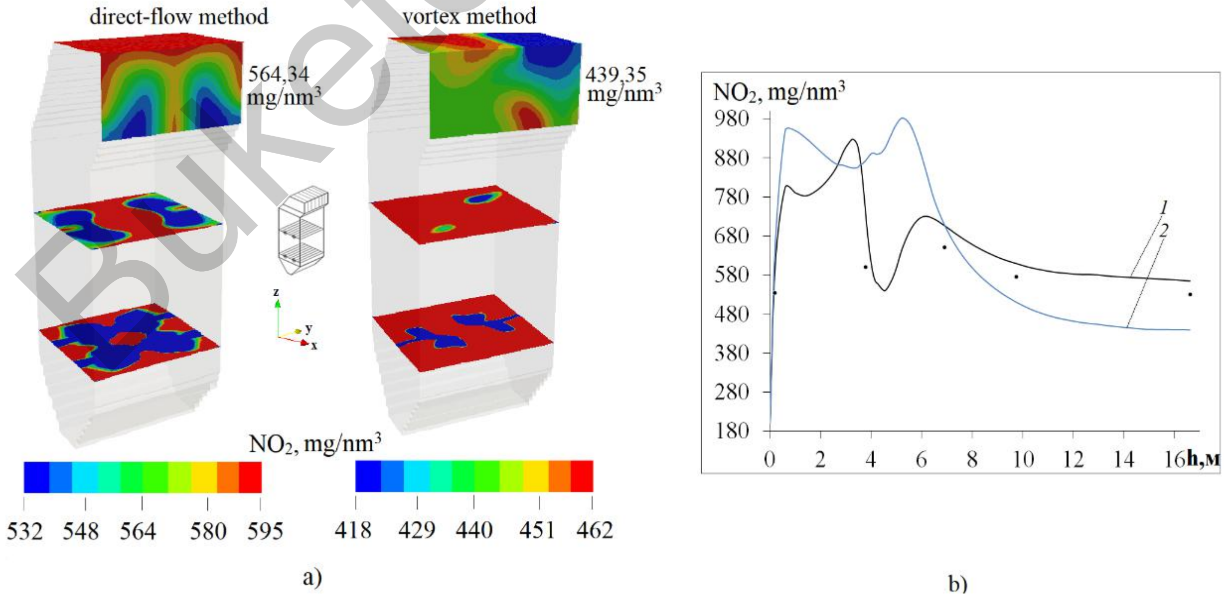
When operating in direct-flow mode, the outlet CO concentration is on average 7.4×10^{-4} kg/kg (Fig. 8a, b; curve 1), whereas for the vortex configuration it decreases to 6.1×10^{-4} kg/kg (Fig. 8a, b; curve 2). Thus, the vortex method reduces CO concentration at the exit by approximately 15% relative to direct flow. Overall, the comes about illustrate that vortex burners upgrade combustion effectiveness by powers in-compartment oxidation forms, bringing down poison outflows at the exit associated to customary direct-flow frameworks. Computational tests created NO_2 concentration areas within the longitudinal (x = 3.0 m) and transverse (h = 4.0 m) segments of the firebox BKZ-75 for both air supply modes (Fig. 9).

The results show that maximum NO_2 formation occurs in regions of elevated temperature and strong vortex motion, located near the burners at h = 4.0 m. Enhanced turbulence from vortex burners improves fuel–oxidizer mixing, while high flame-core temperatures promote NO_2 generation. Under these conditions, the average cross-sectional NO_2 concentration reaches 943 mg/nm^3 (Fig. 9d) compared with 493 mg/nm^3 for non-vortex flow mode (Fig. 9b). Figure 10 shows a uniform decrease in NO_2 concentration toward the combustion chamber exit, reflecting reduced oxygen and fuel availability.



(a) (b) (c) (d)

Fig. 9. Dispersion of nitrogen dioxide NO_2 within the longitudinal (x = 3.0 m) and cross segments of the firebox (burner region, h = 4.0 m) of the BKZ-75 boiler with: direct-flow (a, b) and vortex strategy of providing the discuss blend (c, d).



a) b)

Fig. 10. Three-axis a) and two-axis b) conveyance of the nitrogen dioxide NO_2 along the stature of firebox h of the BKZ-75 evaporator with: bend 1 – direct-flow and bend 2 – vortex way of providing the discuss blend; • – exploratory quantities [25].

With vortex burners, the flat temperature falls along the cavity quickly, assisting in smothering the NO_2 arrangement. Under direct-flow conditions, the NO_2 level at the outlet is 564 mg/nm^3, while in vortex mode it decreases to 439 mg/nm³ (Figs. 10a, b; curves 1 and 2), a reduction exceeding 20%. Exploratory information from the firebox BKZ-75 at Shakhtynskaya TPP [32, 36] confirms these results.

4. Comparisons and discussion

Table 3 presents the comes about of numerical tests for the important parameters of the firebox BKZ-75: temperature (T), carbon monoxide (CO) concentration, and nitrogen dioxide (NO_2) concentration, assessed over distinctive areas of the burning interstellar for both direct-flow and vortex discuss supply approaches. Investigation of the information in Table 1 appears that the utilization of burners with a whirling air-fuel blend outstandingly decreases the normal exit concentrations of destructive substances (CO and NO_2)), aligning them with acceptable limits for the BKZ-75 burning Karaganda coal with high ash content.

Table 3. Cross-sectional normal standards of the most features of the fuel burning handle (T, CO, NO2) at different statures h of the firebox BKZ-75 (burner zone, h = 4 m; at the exit from the heater, h = 16.75 m) amid burning, it covers Karaganda coal with high ash content (fiery debris substance 35,1%)

Height h, m	Air mixture supply methods					
	Direct-flow method of supplying an air mixture			Vortex method of supplying an air mixture		
	Unit			Unit		
	T, °C	CO, kg/kg	NO_2, mg/nm^3	T, °C	CO, kg/kg	NO_2, mg/nm^3
4	620,56	$2.0 \cdot 10^{-3}$	492.48	854.52	$3.1 \cdot 10^{-3}$	943.60
16.75	885.79	$7.4 \cdot 10^{-4}$	564.34	880.02	$6.1 \cdot 10^{-4}$	439.35

Linked with direct-flow jets, vortex burners lower outlet CO levels by about 15% and NO_2 levels by 20%. These discoveries emphasize the viability of vortex jet in improving high-dust coal burning in control plant heaters whereas at the same time diminishing toxin outflows into the atmosphere.

5. Conclusions

1. Mathematical demonstration of warm and mass exchange forms within the firebox of a Kazakhstan warm control plant was achieved for distinctive fuel supply strategies (direct-flow and vortex with a 30° whirl point of the coal-dust stream). A computational demonstration of the BKZ-75 evaporator at the Shakhtinskaya TPP was created, precisely speaking, under the genuine conditions of characteristics of low-rank coal combustion.
2. The influence of pulverized coal swirl on combustion characteristics was scrutinized, counting stream streamlined features (velocity), temperature dispersion, and focuses of burning items (CO and NO_2). Relative comes about are displayed for the direct-flow mode (jets on inverse dividers) and the vortex mode (burners slanted at 30° for the evaporator pivot).
3. Vortex supply of the air–fuel mixture was found to extend the high-temperature zone, increase the flame-core temperature, and reduce outlet temperatures, significantly influencing the chemistry of combustion product formation. This effect is attributed to intensified vortex motion, enhanced convective transfer, and longer residence time of coal particles in the furnace.
4. Vortex burners reduce CO outlet concentrations by ~15% and NO_2 by ~20% compared with direct-flow burners.
5. The close agreement between experimental measurements and numerical predictions confirms the reliability of the proposed combustion chamber model and the methodology for simulating high-temperature reactive flows in real boiler geometries.
6. The results provide a basis for developing recommendations on optimizing pulverized coal combustion, with the dual objectives of improving power plant efficiency and reducing pollutant emissions.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT author statement

Askarova A.S.: Conceptualization, Funding acquisition; **Bolegenova S.A.:** Resources, Supervision; **Nugymanova A.O.:** Visualization, Investigation, Data curation, Writing-Original draft preparation; **Maximov V.Yu.:** Data curation, Methodology; **Bolegenova S.A.:** Software, Validation; **Ospanova Sh.S.:** Writing-Reviewing and Editing; **Shortanbayeva Zh.K.:** Validation; **Aubakirov N.P.:** Software, Writing-Reviewing and Editing; **Nurmukhanova A.Z.:** Supervision.

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References

1 Pan J., Liu G., Chen L., Xu Q. (2025) Coal dust exposure hazards and prevention technology: A review, *Process. Saf. Environ. Prot.,* 202(B), 107756. https://doi.org/10.1016/j.psep.2025.107756

2 Zhakiyev N., Burkhanova D., Nurkanat A., Zhussipkaliyeva Sh., Sospanova A., Khamzina A. (2025) Green energy in grey areas: The financial and policy challenges of Kazakhstan's energy transition, *Energy Res. Soc. Sci.,* 124, 104046. https://doi.org/10.1016/j.erss.2025.104046

3 Tang R., Cheng S. (2023). Combustion chemistry of unsaturated hydrocarbons mixed with NO$_x$: a review with a focus on their interactions, *Energies,* 16(13), 4967. https://doi.org/10.3390/en16134967

4 Bartela L., Gladysz P., Ochmann J., Qvist S., Sancho L.O. (2022). Repowering a coal power unit with small modular reactors and thermal energy storage, *Energies.* 15(16), 5830. https://doi.org/10.3390/en15165830

5 Messerle V.E., Askarova A.S., Bolegenova S.A., Maximov V.Yu., Nugymanova A.O. (2019) 3D-modelling of Kazakhstan low-grade coal burning in power boilers of thermal power plant with application of plasma gasification and stabilization technologies, *J. Phys. Conf. Ser.*, 1261(1), 012022. https://doi.org/10.1088/1742-6596/1261/1/012022

6 Abbas Q., Yaqoob H., Uzair S., Ali H.M., Jamil M.M. (2025) Utilization of local coal in Pakistan's oil-fired power plants and future clean technologies for power generation, *Case Stud. Chem. Environ. Eng.,* 11, 101132. https://doi.org/10.1016/j.cscee.2025.101132

7 Askarova A., Bolegenova S., Mazhrenova N., Manatbayev R., Ospanova Sh., Berezovskaya I., Maximov V., Nugymanova A., Shortanbayeva Z. (2016) 3D modelling of heat and mass transfer processes during the combustion of liquid fuel, *Bulg. Chem. Commun*., 48(E2), 229 – 235. Available at: http://www.bcc.bas.bg/BCC_Volumes/Volume_48_Special_E_2016/Special%20Issue%20E/Statii/Pages229-235.pdf

8 Gao M., Hong F., Yan G., Liu J., Chen F. (2019) Mechanism modelling on the coordinated control system of a coal-fired subcritical circulating fluidized bed unit, *Appl. Therm. Eng.,* 146, 548-555. https://doi.org/10.1016/j.applthermaleng.2018.09.119

9 Hongxin W., Chenyi S., Haidn O., Askarova A., Manfletti Ch., Slavinskaya N. (2023) A joint hydrogen and syngas chemical kinetic model optimized by particle swarm optimization, *Fuel*, 332, 125945. https://doi.org/10.1016/j.fuel.2022.125945

10 Messerle V., Karpenko E.I., Lavrichshev O.A., Ustimenko A. (2013) Plasma preparation of coal to combustion in power boilers, *Fuel Process. Technol.,* 107, 93-98. https://doi.org/10.1016/j.fuproc.2012.07.001

11 Askarova A., Georgiev A., Bolegenova S., Beketayeva M., Maximov V., Bolegenova S. (2022) Computational modeling of pollutants in furnaces of pulverized coal boilers of the Republic of Kazakhstan, *Energy,* 258, 124826. https://doi.org/10.1016/j.energy.2022.124826

12 Liu Ya., Lin B., Liu T., Hao Zh. (2025) Conjugate heat transfer characteristics of crushed coal rock mass under axial compression: Coupling numerical analysis based on CT reconstruction and FEM, *Int. J. Heat Mass Transf.,* 242, 126788. https://doi.org/10.1016/j.ijheatmasstransfer.2025.126788

13 Ustimenko A.B., Messerle V. (2018) Plasma Gasification Energy Conversion Systems, *Comp. Energy Syst.,* 4, 1026-1064. https://doi.org/10.1016/B978-0-12-809597-3.00444-2

14 Liu J., Yu P., Li Y., Wan Ch., Du D. (2022) Numerical simulation on convective heat transfer characteristics in porous media based on the digital rock technology. *Int. J. Heat Mass Transf., 196*, 123323. https://doi.org/10.1016/j.ijheatmasstransfer.2022.123323

15 Feng X.-B., Liu Q., He Ya-L. (2020) Numerical simulations of convection heat transfer in porous media using a cascaded lattice Boltzmann method, *Int. J. Heat Mass Transf.,* 151, 119410. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119410

16 Liu Q., Zhong W., Yu A. (2025) Study on the gas-solid flow and reaction characteristics of oxy-fuel co-firing of coal and biomass in a pressurized fluidized bed by 3D Eulerian-Lagrangian modelling, *Powder Technol.,* 456, 120808. https://doi.org/10.1016/j.powtec.2025.120808

17 Liu X., Tan H., Wang Y., Yang F., Mikulčić H., Vujanović M., Duić N. (2018) Low NOx combustion and SCR flow field optimization in a low volatile coal fired boiler, *J. Environ. Manag.,* 220, 30 - 35.

https://doi.org/10.1016/j.jenvman.2018.05.009

18 Choi M., Park Ye., Li X., Kim K., Sung Y., Hwang T., Cho G. (2021) Numerical evaluation of pulverized coal swirling flames and NO_x emissions in a coal-fired boiler: Effects of co- and counter-swirling flames and coal injection modes, *Energy,* Vol. 217, 119439. https://doi.org/10.1016/j.energy.2020.119439

19 Xia Z., Chen C., Bi J., Li K., Jin Ya. (2016) Modeling and simulation of catalytic coal gasification in a pressurized jetting fluidized bed with embedded high-speed air jets, *Chem. Eng. Sci.,* 152, 624–635. https://doi.org/10.1016/j.ces.2016.06.052

20 Klimanek A., Bigda J. (2018) CFD modelling of CO_2 enhanced gasification of coal in a pressurized circulating fluidized bed reactor, *Energy,* 160, 710 – 719. https://doi.org/10.1016/j.energy.2018.07.046

21 Zhong W., Yu A., Zhou G., Xie J., Zhang H. (2016) CFD simulation of dense particulate reaction system: approaches, recent advances and applications, *Chem. Eng. Sci.,* 140, 16-43. https://doi.org/10.1016/j.ces.2015.09.035

22 Messerle V., Ustimenko A. (2020) Modeling of Coal Ignition in Plasma-Fuel Systems with an Electric Arc Torch, *IEEE Trans. Plasma Sci.,* 48(2), 344 – 349. https://doi.org/10.1109/TPS.2019.2956847

23 Askarova A.S., Bolegenova S.A., Maximov V.Yu., Beketayeva M.T. (2018) Modeling of Heat Mass Transfer in High-Temperature Reacting Flows with Combustion, *High Temp.,* 56(5), 738–743. https://doi.org/10.1134/S0018151X1805005X

24 Wu X., Hu F., Ding C., Yang Y., Yang Ch., Liao H., Lu K., Li B., Liu T., Liu Ch., Li P., Liu Zh. (2024) Progress in numerical simulations and fundamental characteristics of pulverized coal co-firing with ammonia, *Int. J. Hydrog. Energy,* 82, 740 – 758. https://doi.org/10.1016/j.ijhydene.2024.07.456

25 Askarova A.S., Bolegenova S.A., Georgiev A., Bolegenova S.A., Maximov V.Yu., Manatbayev R.K., Yergaliyeva A.B., Nugymanova A.O., Baizhuma Zh.T. (2018) The use of a new "clean" technology for burning low-grade coal in on boilers of Kazakhstan TPPs, *Bulg. Chem. Commun.,* 50, 53 – 60. Available at: http://bcc.bas.bg/BCC_Volumes/Volume_50_Special_G_2018/BCC_50G_PD_2018.Or.pdf#page=51

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