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USE OF TWO-STAGE FUEL COMBUSTION TECHNOLOGY TO MINIMIZE HAZARDOUS EMISSIONS AT KAZAKHSTAN TPP

Abstract. Studies have been carried out using numerical modeling methods to determine the effect of the introduction of a two-stage combustion technology (OFA technology) of high-ash Karaganda coal on the characteristics of combustion processes: aerodynamics of flows, temperature and concentration (COx, NOx) fields throughout the entire volume of the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP and at the outlet from it. Comparison with the basic regime of combustion of pulverized coal fuel, when there is no air supply through additional injectors (OFA = 0%). To implement the technology of two-stage combustion, various regimes of additional air supply through injectors were chosen: OFA equals 0% (basic version, conventional combustion), 5%, 10%, 15%, 18%, 20%, 25% and 30% of total air volume required for fuel combustion. A comparative analysis of the main characteristics of the heat and mass transfer process in the combustion chamber for the investigated modes is carried out. It is shown that an increase in the volume of additional air supplied through the injectors up to 18% leads to a decrease in the concentration of nitrogen oxide NO by 25% in comparison with traditional combustion. A further increase in the volume of additional air leads to a deterioration in these indicators. The results obtained will make it possible to optimize the combustion of low-grade fuel in the combustion chamber of the BKZ-75 boiler, increase the efficiency of fuel burnout, reduce harmful emissions and introduce a two-stage combustion technology at other coal-fired TPPs.

Keywords: numerical simulation, computational experiment, two-stage combustion, high-ash coal, ecology, temperature, nitrogen oxides.

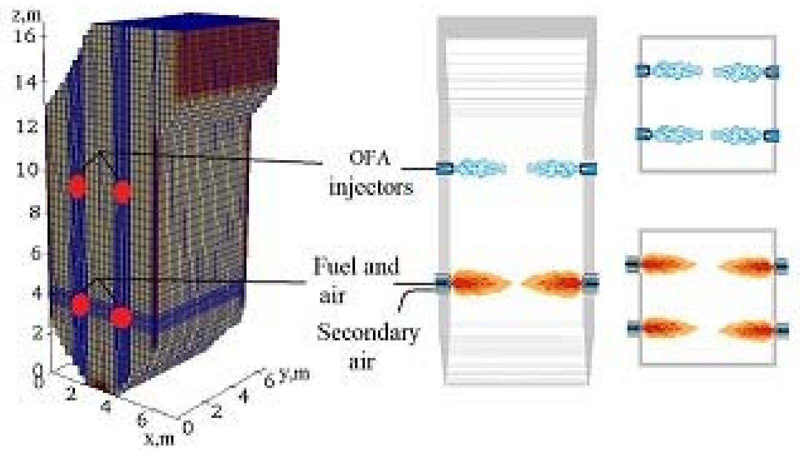
Introduction. Solid fuel power plants remain one of the main sources of environmental pollution with harmful dust and gas emissions. In this regard, it becomes urgent to develop and introduce combustion technologies with minimal emissions of fly ash, carbon oxides and nitrogen at Kazakhstan coal-fired TPPs. Therefore, the main task of the domestic heat power industry is to create technologies for burning high-ash Kazakh coal, with the help of which it is possible to control the main processes of the formation of harmful dust and gas emissions and control the level of their formation [1-5].

In the context of stricter environmental requirements, the introduction of such environmentally friendly coal technologies will allow in the near future to overcome the shortcomings of Kazakhstan coal-fired TPPs significantly increase their efficiency and ensure a sharp decrease in emissions of harmful substances into the atmosphere. Recently, in the world heat power industry, the most popular are information technologies that allow to model new and modernize existing heat power plants, help to assess the feasibility of launching new environmentally outgoing energy production technologies and their economic efficiency at the stage of design solutions. As a rule, everything new first goes through a series of checks, after which it is put into operation on an ongoing basis. The use of computer technologies for the implementation of environmentally friendly coal technologies is especially effective at the initial design stage, when several design solutions are being worked out at the same time and a boiler modernization strategy is being determined [6-11].

Currently, various methods are used to minimize harmful dust and gas emissions at coal-fired TPPs, the main of which are: change in combustion technology and purification of gases after combustion. Changes in combustion technology include: the use of modified burners, afterburning of fuel, recirculation of exhaust gases, staged fuel combustion, preparation of low-grade coals for combustion, radiation technologies, combustion of fuel in fluidized bed furnaces, etc. The method of two-stage fuel combustion is one of the most effective methods for reducing the concentration of harmful emissions and, first of all, the most dangerous of them - nitrogen oxides [12-18].

Description of the combustion chamber for conducting computational experiments.

A real energy object was chosen as the object of research: the combustion chamber of the BKZ-75 boiler of the operating Shakhtinskaya TPP (Shakhtinsk, Kazakhstan). A steam boiler with a capacity of 75 t/h burns high-ash Karaganda coal (ash content 35.10%), is equipped with four pulverized coal burners, two burners from the front and from the rear in one tier. A more detailed description of the boiler combustion chamber, mathematical model, solution method, application package is given in the following works [19-26]. The general view of the combustion chamber of the BKZ-75 boiler (figure 1a) and the arrangement of burners and injectors for the implementation of the technology of two-stage fuel combustion (figure 1b) is shown in figure 1a [27-28].



a) *b)*

Figure 1 – General view of the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP (a) and the layout of burners and OFA injectors (b)

The technology of two-stage fuel combustion is carried out by installing secondary and even tertiary holes (OFA-injectors) to supply additional air above the main combustion zone, when a reduction and afterburner zone is formed in the combustion chamber. In general, with the correct organization of staged combustion, it is possible to reduce the content of nitrogen oxides by about 30-40%. Such a decrease in the formation of nitrogen oxides is explained by the formation of combustion zones in the combustion chamber, characterized by an excess of air and a temperature level.

Results. To implement the technology of two-stage combustion, we have chosen different regimes of supplying additional air through OFA-injectors: OFA is equal to 0% (basic version, traditional combustion), 5%, 10%, 15%, 18%, 20%, 25% and 30% of the total volume of air required for fuel combustion. As a result of the computational experiments, the distributions of temperature T and concentration of nitrogen oxide NO were obtained over the entire volume of the combustion chamber, at the outlet from it, and a comparative analysis was carried out for all studied regimes. Figure 2 shows three-dimensional (figure 2a) and two-dimensional (figure 2b) graphs of the distribution of the cross-sectional average temperature T along the height h of the combustion chamber for the studied regimes of additional air supply.

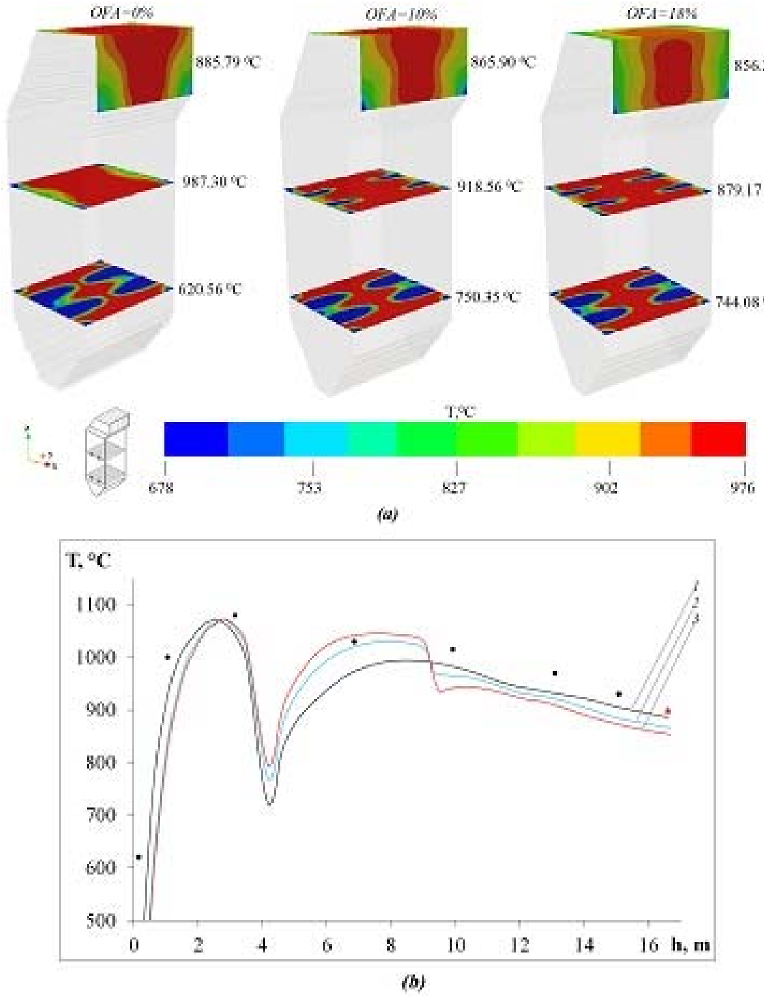


Figure 2 – Three-dimensional a) and two-dimensional b) temperature distribution T along the height h of the chamber of the BKZ 75 boiler at various volumes of air supplied through the injectors:1 – OFA=0%, 2 – OFA=10%, 3 – OFA=18%, ● – CHP experiment [29], ▲ – theoretical value [30]

Analysis of figure 2a shows that with an increase in the volume of air supplied through the injectors, the temperature in the region of the burners (h=4 m) increases: at OFA=10%, T= 750.35^{0}C, at OFA=18%, T= 744.08^{0}C compared with the base case (conventional combustion) when OFA=0%, T=620.56^{0}C. This is due to the fact that when additional air is supplied through the injectors, the area where the burners are located is depleted in oxygen. In addition, this leads to a decrease in the excess air ratio and to an increase in the flame temperature in this zone. On the contrary, more air is supplied in the area of the OFA injectors (h = 9.4 m), chemical reactions are more intense, and the temperature increases in comparison with the temperature in the region of the burner zone: for OFA=0%, T= 987.30^{0}C; OFA=10%, T= 918.56^{0}C and OFA=18%, T= 879.17^{0}C.

This behavior of temperature is clearly seen in figure 2b, which shows its distribution over the height of the combustion chamber of the BKZ-75 boiler at different volumes of air supplied through OFA-injectors. At the outlet from the combustion chamber, we have a further decrease in temperature. Therefore, the average value of the temperature at the outlet from the combustion chamber is for OFA=0%, T=885.79^{0}C; OFA=10%, T=865.90^{0}C and OFA=18% T= 856.27^{0}C. The temperature distribution over the height of the combustion chamber is confirmed by experimental data (figure 2b) obtained directly at the operating Shakhtinskaya TPP [29], and at the outlet from the furnace space, its theoretical value, calculated by the CBTI method [30] for the basic version (OFA=0%). Comparing the results obtained, it can be noted that with an increase in the volume of air supplied through the OFA injectors, a shift in the location of the flame core and an increase in the length of the zone of maximum temperatures are observed (figure 2b, curves 2, 3).

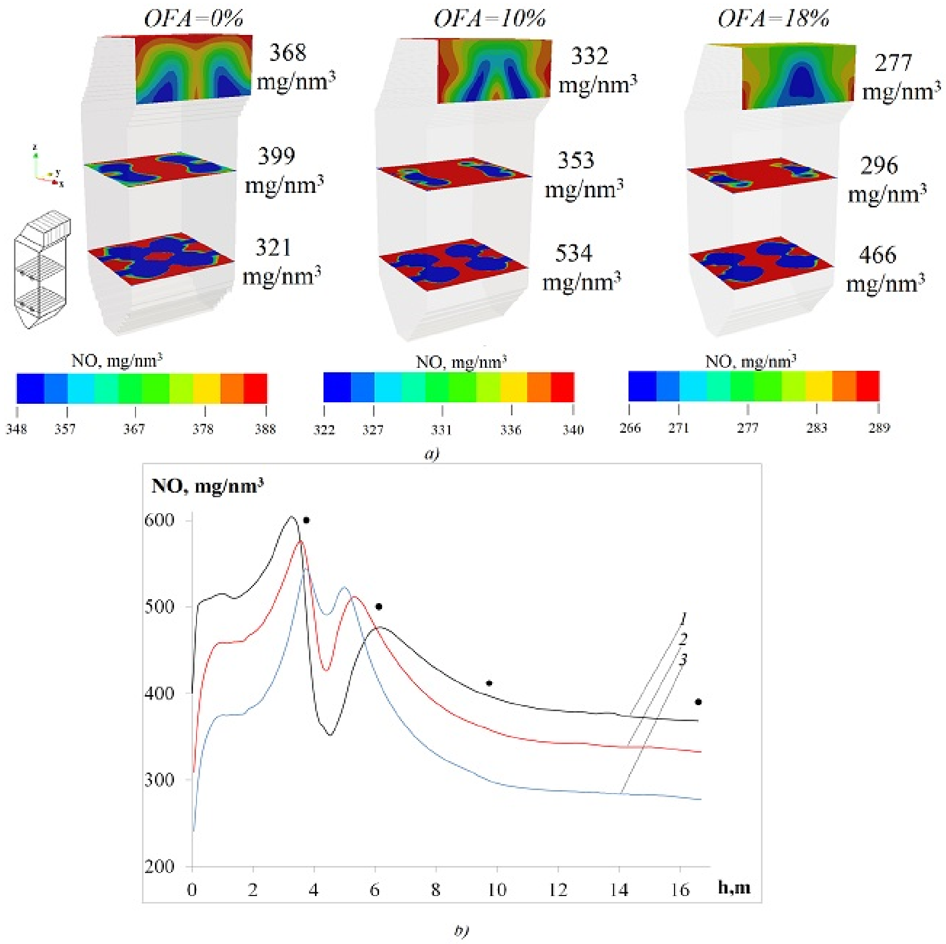


Figure 3 – Three-dimensional (a) and two-dimensional (b) distribution of the concentration of nitrogen oxide NO along the height h of the combustion chamber of the BKZ-75 boiler with different volumes of air supplied through the injectors: *1*–OFA=0%, *2*–OFA=10%, *3*–OFA=18%; ● - experiment at CHP [31]

Figure 3 illustrates the three-dimensional and two-dimensional distribution of the concentrations of nitrogen oxide NO along the height h of the combustion chamber for the studied three cases of application of the two-stage combustion technology. With an increase in the volume of air supplied through the injectors, the amount of nitrogen oxide formed in the area where the burners are located increases (h=4 m) compared to the base case (conventional combustion). So when OFA=0% is 321 mg/nm^3, OFA=10% – 534 mg/nm^3 and OFA=18% – 466 mg/nm^3 (figure 3a).

At the same time, a decrease in the concentration of nitrogen oxide NO is observed in the zone of the location of the injectors at a height of h = 9.4 m when the technology of two-stage combustion is introduced. Here, the average values of the concentration of nitrogen oxide NO for all three cases differ significantly: for the base case OFA=0% the concentration of nitrogen oxide NO is 399 mg/nm^3, at OFA=10% – 353 mg/nm^3 and at OFA=18% – 296 mg/nm^3. This is explained by the fact that in the area of the OFA injectors (h = 9.4 m) a zone enriched with oxygen with a relatively low temperature is created, which leads to a reduced formation of NO from the air (thermal NO_x).

At the outlet from the combustion chamber, with an increase in the volume of air supplied through the injectors, a significant decrease in the concentration of nitrogen oxide no occurs in comparison with the base regime: at ofa=0% – 368 mg/nm^3 (figure 3a and 3b, curve 1), at OFA=10% – 332 mg/nm^3 (figure 3a and 3b, curve 2), at OFA=18% – 277 mg/nm^3 (figure 3a and 3b, curve 3), which is primarily associated with a decrease in temperature in this area of the combustion chamber. All this indicates a significant influence of the technology of two-stage fuel combustion on the distribution of the concentration of solid fuel combustion products in the combustion chamber and at the outlet from it.

Conclusion. Studies have been carried out using 3D computer modeling methods to determine the effect of the introduction of the technology of two-stage combustion of high-ash Karaganda coal on the main characteristics of heat and mass transfer processes: temperature and concentration fields throughout the entire volume of the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP and at the outlet from it.

To implement the two-stage combustion technology, various regimes of additional air supply through the injectors were chosen: OFA equals 0% (basic version, conventional combustion) and when 10%, 18% of the total air volume is supplied to the upper part of the combustion chamber. A comparative analysis of the main characteristics of the heat and mass transfer process in the combustion chamber for the investigated regimes is carried out.

It is shown that an increase in the volume of air supplied through the injectors makes it possible to reduce the concentration of nitrogen oxides NO at the outlet from the combustion space. The use of the technology of two-stage combustion in the combustion chamber of the BKZ-75 boiler at the Shakhtinskaya TPP leads to a significant decrease in the concentration of nitrogen oxide NO. In our case, one of the optimal options for reducing the concentration of nitrogen oxides NO at the outlet from the combustion chamber is the use of injectors at OFA=18%.

The results obtained will make it possible to optimize the combustion of low-grade fuel in the combustion chamber of the BKZ-75 boiler, increase the efficiency of fuel burnout, reduce emissions of harmful substances into the environment and introduce a two-stage combustion technology at other coal-fired TPPs.

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ҚАЗАҚСТАНДЫҚ ЖЭО ЗИЯНДЫ ШЫҒАРЫНДЫЛАРДЫ АЗАЙТУ ҮШІН ОТЫНДЫ ЕКІСАТЫЛЫ ЖАҒУ ТЕХНОЛОГИЯСЫН ПАЙДАЛАНУ

Аннотация. Қатты отынмен жұмыс істейтін электр станциялары – қоршаған ортаны зиянды шаң-газ шығарындысымен ластаудың негізгі көздерінің бірі болып қала береді. Азот оксидтерін бәсеңдету бойынша сандық тәжірибелер жүргізу үшін екі сатылы жағу технологиясы арқылы Шахтинск ЖЭО (Шахтинск қ., Қазақстан) БКЗ-75 қазандығының жағу камерасы таңдалды. Қазандықта Қарағанды көмірінің шаңы жағылады, күлі 35,10%, ұшпа 22%, ылғалдылығы 10,6% және жану жылуы 18,55 МДж/кг. Екісатылы жану технологиясын жүзеге асыру үшін инжекторлар арқылы қосымша ауа берудің түрлі режимдері таңдалды: OFA 0% (базалық нұсқа) және 10%, ауаның жалпы көлемінің 18% пештің жоғарғы жағындағы инжекторлар арқылы беріледі.

Жүргізілген сандық эксперимент нәтижесінде БКЗ-75 қазандығының жану камерасының бүкіл көлемі бойынша және шығысында NO азот оксидінің температуралық және концентрациялық өрісі алынды. Зерттелетін режимдерге арналған жану камерасындағы жылу беру үдерісінің негізгі сипаттамаларына салыстырмалы талдау жүргізілді. Инжекторлар арқылы жеткізілетін қосымша ауа көлемінің 18%-ға артуы NO азот оксиді концентрациясының базалық жағдайға (дәстүрлі жану) қарағанда 25%-ға төмендететіні көрсетілген. Алынған нәтижелер БКЗ-75 қазандығының от жағу камерасында төмен сұрыпты отынды жағу үдерісін оңтайландыруға, отынның жану тиімділігін арттыруға, қоршаған ортаға зиянды шығарындыларды азайтуға және басқа да көмір жағатын ЖЭО-да екісатылы жағу технологиясын енгізуге мүмкіндік береді.

Түйін сөздер: сандық модельдеу, есептеу эксперименті, екі сатылы жану, күлі жоғары көмір, экология, температура, азот оксидтері

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ИСПОЛЬЗОВАНИЕ ТЕХНОЛОГИИ ДВУХСТУПЕНЧАТОГО СЖИГАНИЯ ТОПЛИВА ДЛЯ МИНИМИЗАЦИИ ВРЕДНЫХ ВЫБРОСОВ НА КАЗАХСТАНСКИХ ТЭЦ

Аннотация. Одним из основных источников загрязнения окружающей среды вредными пылегазовыми выбросами остаются электростанции, работающие на твердом топливе.

Для проведения численных экспериментов по подавлению оксидов азота с помощью технологии двухступенчатого сжигания была выбрана топочная камера котла БКЗ-75 Шахтинской ТЭЦ (г. Шахтинск, Казахстан). В котле сжигается пыль карагандинского угля, зольностью 35,10%, выходом летучих 22%, влажностью 10,6% и теплотой сгорания 18,55 МДж/кг. Для реализации технологии двухступенчатого сжигания выбраны различные режимы подачи дополнительного воздуха через инжекторы: OFA равно 0% (базовый вариант) и 10%, 18% от общего объема воздуха подается через инжекторы в верхней части топки.

В результате проведенных численных экспериментов были получены температурные поля и концентрационные поля оксида азота NO по всему объему и на выходе топочной камеры котла БКЗ-75. Проведен сравнительный анализ основных характеристик процесса тепломассопереноса в топочной камере для исследуемых режимов. Показано, что увеличение объема дополнительного воздуха, подаваемого через инжекторы, до 18% приводит к уменьшению концентраций оксида азота NO на 25% по сравнению с базовым случаем (традиционное сжигание). Полученные результаты позволят оптимизировать процесс сжигания низкосортного топлива в топочной камере котла БКЗ-75, повысить эффективность выгорания топлива, уменьшить вредные выбросы в окружающую среду и внедрить технологию двухступенчатого сжигания на других углесжигающих ТЭЦ.

Ключевые слова: численное моделирование, вычислительный эксперимент, двухступенчатое сжигание, высокозольный уголь, экология, температура, оксиды азота.

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