NEWS
OF THENATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
PHYSICO-MATHEMATICAL SERIES
ISSN 1991-346X **https://doi.org/10.32014/2019.2518-1726.71**
Volume 6, Number 328 (2019), 34 – 42

UDC 536.46:532.517.4
IRSTI 29.03.77; 29.03.85

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OPTIMIZATION OF THE SOLID FUEL COMBUSTION PROCESS IN COMBUSTION CHAMBERS IN ORDER TO REDUCE HARMFUL EMISSIONS

Abstract. The methods of numerical simulation are used to study the processes of heat and mass transfer in the combustion chamber of an operating coal-burning Kazakhstan thermal power plant. Computational experiments were performed on the combustion of high-ash Karaganda coal in the combustion chamber of the BKZ-75 boiler (Shakhtinsk, Karaganda region). As a result of numerical simulation of the combustion processes, the distributions of the total velocity vector, temperature fields, concentration fields of nitrogen oxides NO over the entire volume of the combustion chamber and at its exit were obtained. A comparative analysis of the characteristics of heat and mass transfer processes for the two studied modes of supplying fuel to the combustion chamber through burner devices is given for the direct-flow method of supplying the mixture when the burners are located on opposite side walls and the vortex method of supplying the mixture when the burners are installed at a 30-degree angle from the center of symmetry of the boiler. It is shown that the vortex method of supplying air mixtures allows optimizing the combustion of high-ash coal, since in this case there is an increase in temperature in the core of the torch and a decrease in it at the exit from the combustion chamber, which has a significant effect on the chemical processes of the formation of combustion products. The average value of the concentration of nitrogen oxide NO at the outlet of the combustion chamber decreases when using burner devices with a swirl of the mixture flow and conforms to norms the maximum permissible concentration.

Key words. numerical simulation, solid fuel, combustion chamber, direct-flow and vortex methods of supplying air mixtures, velocity, temperature, nitrogen oxides.

Introduction

The development of the fuel and energy complex and energy is one of the most important foundations for the development of all modern material production. Countries with the necessary resources and the ability to develop long-term plans for their use receive undeniable competitive advantages. The issue of choice, operation, and, first of all, the creation of new, highly efficient energy and resource-saving technologies becomes relevant for the heat power industry [1-2].

In this paper, using modern 3D modeling technologies [3-11], a comprehensive study of the thermal processes and aerodynamic characteristics of the combustion chamber of an existing Kazakhstan energy facility (Shakhtinskaya TPP, Kazakhstan) is carried out.. Based on the numerical solution of the system of convective heat and mass transfer equations [12-13], taking into account the kinetics of chemical reactions, two-phase flow, nonlinear effects of convective and radioactive heat transfer, and 3D modeling

methods, aerodynamic, thermal, and concentration characteristics are obtained over the entire volume of the combustion chamber, in its main sections and at the exit [14-21].

A comparative analysis of the characteristics of heat and mass transfer processes for the two studied modes of supplying fuel to the combustion chamber through burner devices is given for the direct-flow method of supplying the mixture when the burners are located on opposite side walls and the vortex method of supplying the mixture when the burners are installed at a 30^0 angle from the center of symmetry of the boiler.

The results of the studies allow us to develop appropriate technological solutions for installing burner devices (direct-flow or vortex) in the combustion chamber under study and to optimize the process of burning high-ash Kazakhstan coal in order to minimize harmful emissions into the atmosphere.

2. Description of the combustion chamber for conducting computational experiments

For conducting numerical experiments, the combustion chamber of the BKZ-75 boiler was installed at the Shakhtinskaya TPP (Shakhtinsk, Kazakhstan), in which Karaganda coal with an ash content of 35.1% is burned. Steam boiler BKZ-75 - vertically water-tube, productivity 75 t/h (51.45 Gcal/h) [22-27]. The boiler is equipped with four pulverized coal burners installed in two burners from the front and from the rear in one tier. Figure 1 shows the finite-difference grid for conducting computational experiments and the design of various burner devices (direct-flow and vortex) of the combustion chamber of the BKZ-75 boiler.

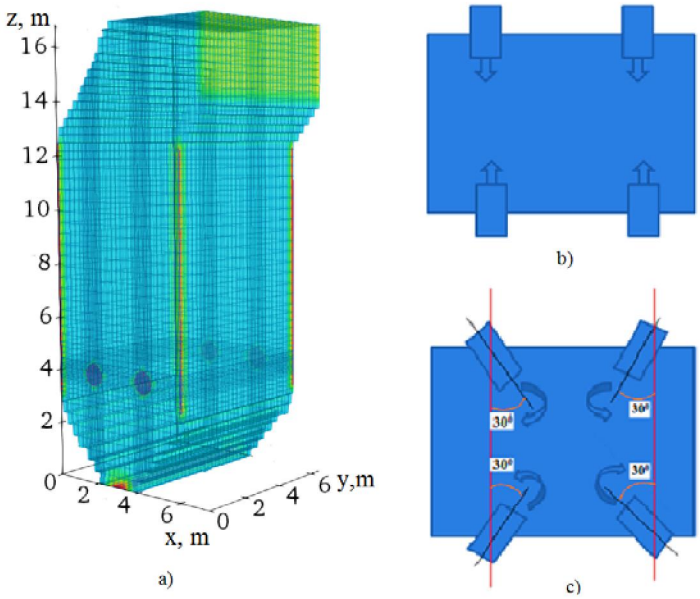


Figure 1 - Finite-difference grid of the combustion chamber of the boiler BKZ-75 of the Shakhtinskaya TPP and designs of burner devices of the combustion chamber of the boiler
BKZ-75: a) straight-through burners; b) burners with a spin of the flow of the air mix

To carry out computational experiments in the combustion chamber of the BKZ-75 boiler, two cases were investigated 1) a direct-flow method of supplying air mixtures – burners are located on opposite side walls; 2) the vortex method of supplying the mixture - burners with a swirl angle of the mixture flow and tilting them to the center of symmetry of the boiler by 30^0.

3. Results

This work presents the results of computational experiments, the distribution of the full velocity vector, the temperature and concentration fields of nitrogen oxide NO for two cases of fuel supply to the combustion chamber of the BKZ-75 boiler (direct-flow and vortex). Figure 2 shows the distribution of the total velocity vector in longitudinal sections of the combustion chamber of the BKZ-75 boiler. We see that in the direct-flow method of supplying air mixtures, the flows, colliding in the center at a right angle, are cut in the region of the cold funnel and towards the exit from the combustion chamber, with the formation of a vortex flow of lower intensity. With the vortex method of supplying the air mixture, four swirling

flows in the region of the belt of the burner devices guiding from the burners collide with each other in the central part of the combustion chamber at an angle of 30^0. Then, having united in two main streams, they are dissected, forming vortex flows of flow more in the horizontal region of the combustion chamber. High stability of the vortex flow (vortex) position increases the residence time of coal dust in the combustion zone will significantly reduce the formation of the concentration of harmful substances.

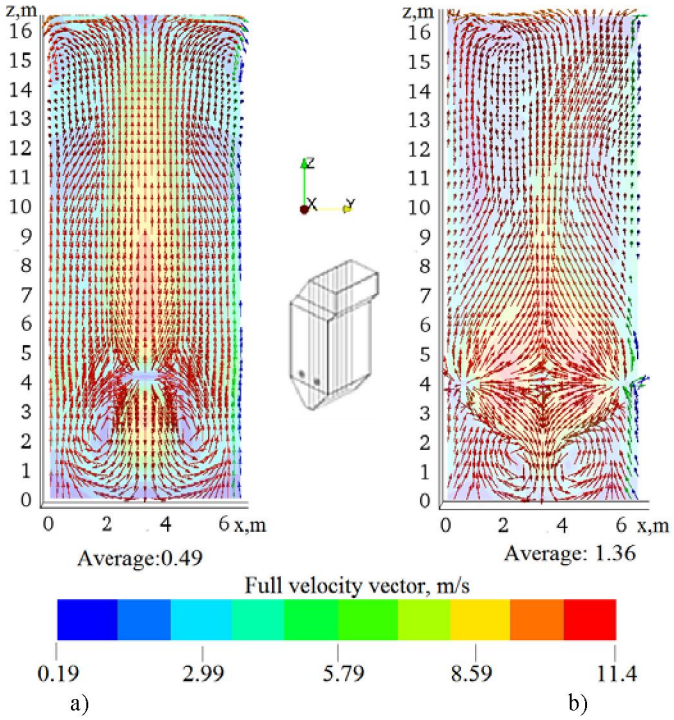


Figure 2. The distribution of the field of the full velocity vector in longitudinal sections (x=3) of the combustion chamber of the boiler BKZ-75:
a) direct-flow method of supplying air mixture; b) vortex method of supplying air mixture

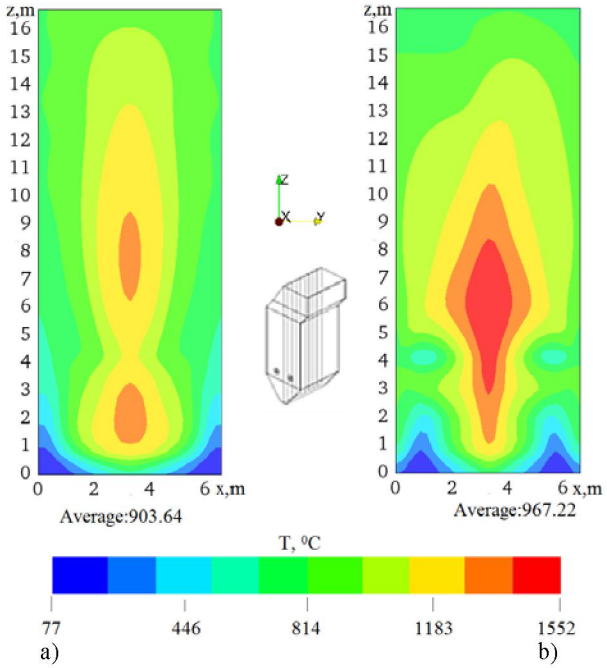


Figure 3 - The distribution of the field of the temperature in longitudinal sections (x=3) of the combustion chamber of the boiler BKZ-75:
a) direct-flow method of supplying air mixture; b) vortex method of supplying air mixture

Figure 3 illustrates the temperature field in the longitudinal sections of the combustion chamber of the BKZ-75 boiler for the two studied modes of supply of air mixture (direct-flow and vortex). We see that the temperature has maximum values in an area close to the location of the burner devices. With the direct-flow method of supplying the air mixture, the average temperature in the longitudinal section (x=3) of the combustion chamber of the BKZ-75 boiler is 903.64°C, and in the case of a vortex feed of a mixture, the temperature value increases and amounts to 967.22°C. This is due to the vortex nature of the flow, providing maximum convective transport and an increase in the residence time of coal particles in the combustion chamber of the BKZ-75 boiler.

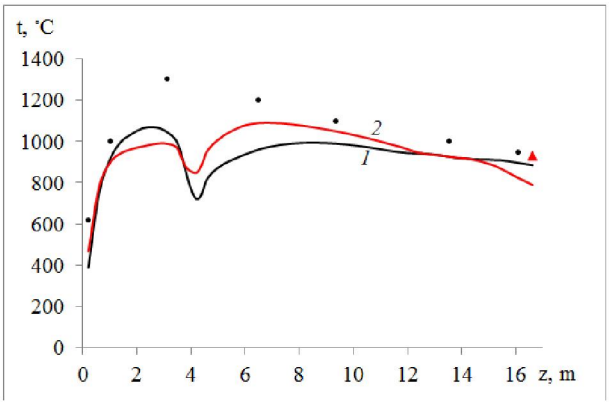
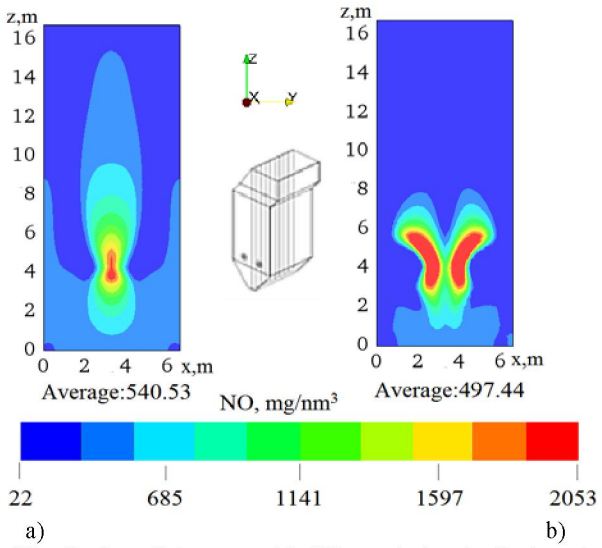


Figure 4 - Temperature distribution along the height of the combustion chamber the BKZ-75 boiler with: 1– direct-flow method of supplying air mixture; 2 – vortex method of supplying air mixture; ● - experimental data at TPPs [28]; ▲ – is theoretical values obtained by the method of thermal calculation (CBTI – Central Boiler-and-Turbine Institute) [29]

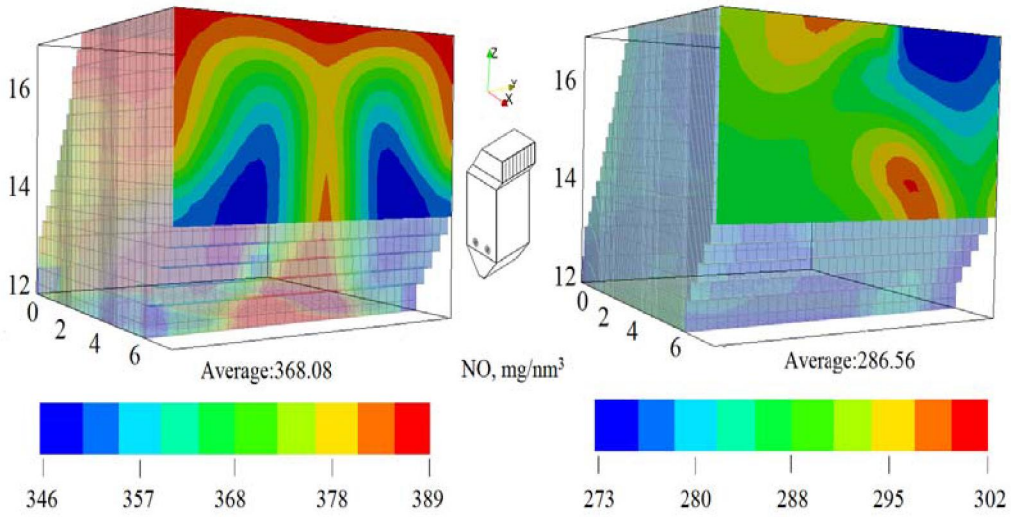
Figure 4 shows a comparative analysis of the distribution of the average temperature in the cross section over the height of the combustion chamber for the two studied modes of supply of air mixture (direct-flow and vortex). In the case of a vortex feed of an air mixture, an increase in the extent of the zone of maximum temperatures is observed. The minimum in the curves associated with the low temperature of the air mixture entering the combustion chamber through the burners. An increase in the temperature in the core of the flame and a decrease in its output exerts a significant effect on the chemical processes of the formation of combustion products. The temperature at the outlet of the combustion chamber is confirmed by its theoretical value calculated by the CBTI method for direct-flow supply of air mixture [29].

Distributions of nitrogen oxide NO concentrations in different sections of the combustion chamber are presented in the Figures 5-6.



a) b)

Figure 5 - Distribution of nitrogen oxide NO area in longitudinal sections (x=3) of the combustion chamber the BKZ-75 boiler with:
a) direct-flow method of supplying air mixture; b) vortex method of supplying air mixture



a) b)

Figure 6 - Distribution of nitrogen oxide NO at the outlet of the combustion chamber the boiler BKZ-75 with: a) direct-flow method of supplying air mixture; b) vortex method of supplying air mixture

As can be seen from the figures, the zone of maximum formation of nitrogen oxide NO is the region of high temperatures and intense vortex flow. Intensive mixing of fuel and oxidizing agent, created by turbulent flows of injected air mixture near the burners, as well as high temperature in the torch core, create favorable conditions for the formation of nitrogen oxides. The average value of the concentrations of nitrogen oxide NO in this region is equal to the direct-flow method of supplying air mixture – 540.53 mg/nm^3 (Figure 5a), and with a vortex method of supplying air mixtures – 497.44 mg/nm^3 (Figure 5b).

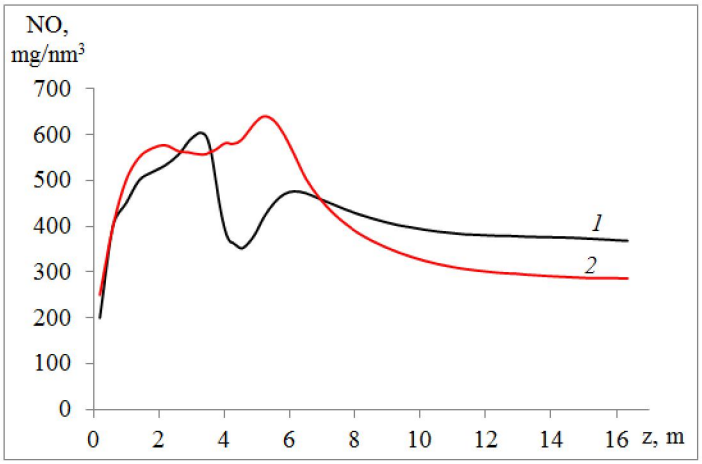


Figure 7 - Distribution the concentration of nitrogen oxide NO at the outlet of the combustion chamber the boiler BKZ-75 with: 1 - direct-flow method of supplying air mixture nitrogen oxide NO; 2 - vortex method of supplying air mixture nitrogen oxide NO

However, towards the exit from the combustion chamber (Figures 6-7), a uniform decrease in the NO concentration is observed, since this region contains less oxygen and a fuel component. In addition, in the case of using burner devices with swirling of the mixture flow, the temperature along the height of the combustion chamber monotonously decreases, as a result of which the rate of formation of nitrogen oxide NO. At the exit from the combustion chamber, the average value of the concentration of nitrogen oxide NO with a direct-flow method of supplying air mixture is 368.08 mg/nm^3 (Figure 6a and 7a, curve 1), and with vortex burner devices – 286.56 mg/nm^3 (Figure 6b and 7b, curve 2), that on 81 mg/nm^3 less.

The results indicate the advantages of choosing a vortex method of supplying air mixtures to optimize the combustion of high-ash coal in the combustions of power plants and reduce harmful dust and gas emissions into the environment.

Conclusion

The methods of numerical simulation are used to study the processes of heat and mass transfer in the combustion chamber of an active coal-burning Kazakhstan TPP. Computational experiments were performed on the combustion of high-ash Karaganda coal in the combustion chamber of the BKZ-75 boiler (Shakhtinsk, Karaganda region).

As a result of the numerical simulation of the combustion processes during the combustion of high-ash coal, the distributions of the total velocity vector, temperature fields, concentration fields of nitrogen oxides NO over the entire volume of the combustion chamber of the boiler and at its exit were obtained.

A comparative analysis of the characteristics of heat and mass transfer processes for the two studied modes of supplying fuel to the combustion chamber through burners with a direct-flow method of supplying the mixture when the burners are located on opposite side walls and a vortex method (swirling flow) of the mixture supplying when the burners are installed with their slope to the center of symmetry of the boiler is presented 30^0.

The vortex method of supplying the mixture allows to optimize the combustion of high-ash coal, due to the circulation movement, the residence time of the fuel particles in the combustion chamber increases, there is an increase in temperature in the flame core and its decrease at the exit of the combustion chamber, which has a significant effect on the chemical processes of the formation of combustion products. In this case, the average value of the concentration of nitrogen oxide NO when using burner devices with a swirl of the mixture flow at the outlet of the combustion chamber decreases and corresponds to the norms of maximum permissible concentration.

Acknowledge

This work was supported by Ministry of Education and Science of the Republic of Kazakhstan (grants AP05132988 and AP05133590 and BR05236730).

The author, P.Safarik, expresses thanks for support by the Project No. CZ.2.16/3.1.00/21569 Centre 3D Volumetric Anemometry.

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ЗИЯНДЫ ҚАЛДЫҚТАРДЫ АЗАЙТУ МАҚСАТЫНДА ЖАНУ КАМЕРАСЫНДА ҚАТТЫ ОТЫНДЫ ЖАҒУ ПРОЦЕСІН ОҢТАЙЛАНДЫРУ

Аннотация. ЖЭО-ның қазақстандық қолданыстағы көмір жағатын жану камерасында жылу және масса алмасуын сандық модельдеу әдістерімен зерттелді. БКЗ-75 (Шахтинск, Қарағанды облысы) қазандығының жану камерасында жоғары күлді Қарағанды көмірін жағу кезінде есептеу тәжірибелері жүргізілді. Жану процестерін сандық модельдеудің нәтижесінде мыналар алынды: жылдамдық векторының толық таралуы, температуралық өріс, NO азот оксидтерінің концентрациялық өрістерінің жану камерасының барлық көлемінде және оның шығысында. Жану камерасына оттық құрылғылар арқылы жанармай жеткізудің екі режимі жылу және масса алмасу процестерінің сипаттамаларына салыстырмалы үшін зерттеліп талдау ұсынылған: оттықтар қарама-қарсы жақ қабырғаларында орналасқан кезде ауа қоспасын берудің тікелей әдісі және қыздырғыштар өздерінің градусымен 30 градусқа бейімделген күйде орнатылған кезде ауа

қоспасын берудің құйынды әдісі ұсынылған. Құйынды ауа қоспасын беру әдісі жоғары күлді көмірдің жануын оңтайландыруға мүмкіндік береді, өйткені бұл жағдайда алау өзегіндегі температураның жоғарылауы және жану камерасынан шыққан кезде оның төмендеуі байқалады, жану өнімдерінің пайда болуының химиялық процестеріне айтарлықтай әсер етеді. Азот оксиді NO концентрациясының орташа мәні жану камерасының шығысындағы қоспаның ағынының серпілісімен қыздырғыш құрылғыларды пайдалану кезінде төмендейді және ПӘК сәйкес келеді.

Түйін сөздер. Сандық моделдеу, қатты отын, жану камерасы, ауа қоспаларын берудің тікелей ағынды және құйынды әдістері, жылдамдық, температура, азот оксидтері

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ОПТИМИЗАЦИЯ ПРОЦЕССА СЖИГАНИЯ ТВЕРДОГО ТОПЛИВА В ТОПОЧНЫХ КАМЕРАХ С ЦЕЛЬЮ СНИЖЕНИЯ ВРЕДНЫХ ВЫБРОСОВ

Аннотация. Методами численного моделирования исследованы процессы тепломассопереноса в топочной камере действующей углесжигающей казахстанской ТЭЦ. Выполнены вычислительные эксперименты по сжиганию высокозольного карагандинского угля в камере сгорания котла БКЗ-75 (г. Шахтинск, Карагандинская область). В результате проведения численного моделирования топочных процессов были получены: распределения вектора полной скорости, температурные поля, поля концентраций оксидов азота NO по всему объему топочной камеры и на выходе из нее. Представлен сравнительный анализ характеристик процессов тепломассопереноса для двух исследуемых режимов подачи топлива в камеру сгорания через горелочные устройства: прямоточный способ подачи аэросмеси, когда горелки расположены на противоположных боковых стенках и вихревой способ подачи аэросмеси, когда горелки установлены с наклоном их к центру симметрии котла на 30 градусов. Показано, что вихревой способ подачи аэросмеси позволяет оптимизировать процесс сжигания высокозольного угля, поскольку в этом случае наблюдается увеличение температуры в ядре факела и снижение ее на выходе из камеры сгорания, что оказывает существенное влияние на химические процессы образования продуктов горения. Среднее значение концентрации оксида азота NO на выходе из топочной камеры уменьшается при использовании горелочных устройств с закруткой потока аэросмеси и соответствует нормам ПДК.

Ключевые слова. Численное моделирование, твердое топливо, камера сгорания, прямоточный и вихревой способы подачи аэросмеси, скорость, температура, оксиды азота.

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