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STUDY OF THE AERODYNAMICS OF THE FLOW OF THE COMBUSTION CHAMBER OF A POWER PLANT WITH VARIOUS SUPPLY OF SOLID FUEL

Numerical modeling methods have been used to study the effect of an emergency stop of the fuel mixture supply through individual burners on the aerodynamics of the flow in the combustion chamber of a power boiler. The performed computational experiments made it possible to obtain the main aerodynamic characteristics of heat and mass transfer processes (full velocity vector, pressure, kinetic energy of turbulence and dissipation energy) in the volume of the combustion chamber and at the exit from it in emergency mode (two swirl burners are operating) and compare them with traditional solid fuel combustion (basic mode - four direct-flow burners are working). The results obtained indicate that with a vortex fuel supply in the central region of the combustion chamber, a sharp change in aerodynamic characteristics is observed with the formation of a vortex flow, which weakens as the pulverized coal flow and combustion products move to the exit. The presence of a vortex flow causes stable combustion of solid fuel and uniform distribution of heat flows along the walls of the combustion chamber. In addition, the vortex nature of the flow increases the residence time of coal particles in the combustion chamber, which contributes to a more complete burnout and a decrease in the mechanical underburning of the fuel mixture. Such a detailed study of the aerodynamic flow pattern that takes place in the combustion chamber of power boilers of operating TPPs can only be obtained by numerical simulation methods and by performing computational experiments. The highly informative results obtained make it possible to develop “clean” energy production technologies and solve environmental problems of the emission of harmful substances into the environment.

Keywords: numerical simulation, combustion chamber, turbulence model, velocity, pressure.

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Қатты отынды әртүрлі беруге негізделген ЖЭС жану камерасындағы ағыстың аэродинамикасын зерттеу

Сандық модельдеу әдістерімен энергетикалық қазандықтың жану камерасындағы ағыс аэродинамикасына жекелеген жанарғы құрылғылары арқылы отын аэроқоспасы берілуінің апаттық кідірісінің әсері зерттелінді. Жүргізілген есептеу тәжірибелері жану камерасының көлемінде және одан шыққан кезде апаттық режимде (екі құйынды жанарғы жұмыс істейді) жылумасса тасымалы процестерінің негізгі аэродинамикалық сипаттамаларын (толық жылдамдық векторы, қысым, турбуленттіліктің кинетикалық энергиясы және диссипация энергиясы) алуға және оларды қатты отынды дәстүрлі жағумен салыстыруға (базалық режим – төрт тура ағынды жанарғы жұмыс істейді) мүмкіндік берді. Алынған нәтижелер жану камерасының орталық облысында құйын жеткізілуімен ағыстың аэродинамикалық сипаттамалардың күрт өзгеруі байқалатындығын көрсетті, құйынды ағын пайда болады, соңғысы шаңкөмірлі ағын мен жану өнімдерінің шығысқа қарай жылжу деңгейімен әлсірей түседі. Құйынды ағыстың болуы қатты отынның тұрақты жануын және жану камерасының қабырғалары бойынша жылу ағындарының біркелкі таралуын қамтамасыз етеді. Сонымен қатар ағынның құйынды сипаты көмір бөлшектерінің жану камерасында болу уақытын арттырады, бұл отын аэроқоспасының толық жанып бітуіне және механикалық жанудың толымсыздығының төмендеуіне ықпал етеді. ЖЭС энергетикалық қазандықтарының жану камерасында жүзеге асатын ағынның аэродинамикалық бейнесін мұқият зерттеулерді тек сандық модельдеу әдістерімен және есептеу тәжірибелерін жүргізу арқылы алуға болады. Алынған жоғары ақпараттық нәтижелер энергия өндірудің «таза» технологияларын әзірлеуге және қоршаған ортаға зиянды заттар шығарылуының экологиялық проблемаларын шешуге мүмкіндік береді.

Түйін сөздер: сандық модельдеу, жану камерасы, турбуленттілік моделі, жылдамдық, қысым.

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Исследование аэродинамики течения камеры сгорания ТЭС с различной подачей твердого топлива

Методами численного моделирования проведено исследование влияния аварийной остановки подачи топливной аэросмеси через отдельные горелочные устройства на аэродинамику течения в камере сгорания энергетического котла. Выполненные вычислительные эксперименты позволили получить основные аэродинамические характеристики процессов тепломассопереноса (вектор полной скорости, давление, кинетическая энергия турбулентности и энергия диссипации) в объеме камеры сгорания и на выходе из нее при аварийном режиме (работают две вихревые горелки) и сравнить их с традиционным сжиганием твердого топлива (базовый режим – работают четыре прямоточные горелки). Полученные результаты свидетельствуют о том, что при вихревой подаче топлива в центральной области камеры сгорания наблюдается резкое изменение аэродинамических характеристик с образованием вихревого течения, которое ослабевает по мере продвижения пылеугольного потока и продуктов горения к выходу. Наличие вихревого течения обуславливает стабильное горение твердого топлива и равномерное распределение тепловых потоков по стенкам топочной камеры. Кроме того, вихревой характер течения увеличивает время пребывания угольных частиц в камере сгорания, что способствует более полному выгоранию и снижению механического недожога топливной аэросмеси. Такое подробное исследование аэродинамической картины течения, имеющей место в камере сгорания энергетических котлов действующих ТЭС, можно получить только методами численного моделирования и путем проведения вычислительных экспериментов. Полученные высокоинформативные результаты позволяют разрабатывать “чистые” технологии производства энергии и решать экологические проблемы выброса вредных веществ в окружающую среду.

Ключевые слова: численное моделирование, камера сгорания, модель турбулентности, скорость, давление.

Introduction

The problem of greenhouse gas emissions has now grown into a common human problem associated with global climate change on earth, flooding of vast land areas, desertification, etc. The greatest harm to the environment is caused by enterprises of heat power engineering, oil and gas industry and mechanical engineering. The share of energy enterprises in the total volume of environmental pollution by fuel combustion products is quite large.

This problem is especially acute for Kazakhstan since coal is the main source of heat and electricity in the republic. Coal is the most abundant natural resource. A positive moment in the use of this type of fuel is its huge natural reserves, exceeding the reserves of oil and natural gas. In the context of a constant rise in the cost of hydrocarbon energy carriers, the use of coal is the most economically profitable in various sectors of the economy of the Republic of Kazakhstan, especially in coal-mining regions. Coal-fired TPP plants use low-grade Kazakh coal with high ash content (30-50%), moisture (30-40%), sulfur content (1-3%) and low volatiles (5-15%). Its combustion causes substantial environmental problems, including a rise in toxic dust and gas emissions, as well as a deterioration of fuel ignition and burnout [1, 2].

Today, the question of the design and safety of a solid fuel combustion system is especially acute for boilers during their modernization or during the construction of power units "from scratch". The tool for mathematical 3D modeling of complicated heat and mass transfer processes in operational boiler combustion chambers is becoming increasingly popular, allowing you to assess offered technological solutions subjectively and quantitatively, as well as perform independent study.

However, sufficient precise and useful knowledge regarding the regularities of the occurrence of physical and chemical events under conditions like natural ones, as well as physical and kinetic characteristics that can only be gathered by experiments, is required for its application. A complete and accurate description of all ongoing processes in steam generators, furnaces, together with modern computational algorithms and using modern computer technology, make it possible to solve these problems for specific power plants [3, 4].

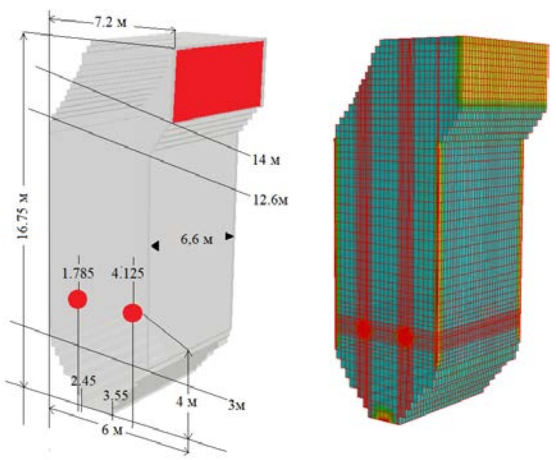
In the boiler unit during operation, damage can occur, malfunctions can occur that create dangerous situations, fraught with failure of the equipment or the boiler unit, destruction with large material losses and human casualties. Elimination of detected violations and defects is possible, considering damage, without stopping the boiler unit or with its obligatory immediate stop.

The shutdown of the boiler can be divided into three groups: planned, short-term and emergency, depending on the circumstances. Planned (complete) shutdown of the boiler is carried out according to the schedule, a short-term shutdown of the boiler unit may be caused by a violation of its normal operation due to equipment malfunction or for other reasons that can cause an accident [5, 6]. When the steam pressure in the boiler rises above the permissible level, due to a malfunction of the pressure sensor and all water-indicating devices, the presence of significant damage to the boiler's elements, or the detection of abnormalities in the boiler's operation, an emergency shutdown of the boiler may occur. [7-9].

Below are the results of computational experiments on the study of heat and mass transfer processes using the example of a real BKZ-75 boiler at Shakhtinskaya TPP, in the furnace of which high-ash Karaganda coal is burned with an ash content of 35.10%. Various methods of solid fuel supply (basic and emergency mode) are considered and the main characteristics are determined that describe the aerodynamics of the flow in the furnace space.

Research Object

The combustion chamber of the BKZ-75 boiler at the Shakhtinskaya TPP was chosen for numerical testing (Figure 1). The BKZ-75 boiler's furnace chamber is equipped with four axial-blade vortex pulverized-coal burners, which are arranged in two stages on the chamber's side walls, with direct dust injection from separate dust preparation systems. The boiler uses dust from Karaganda coal, which has a 35.10 percent ash content, a 22 percent volatile output, a 10.6 percent moisture content, and a heat of combustion of 18.55 MJ/kg. Table 1 shows the key structural features of the BKZ-75 boiler's combustion chamber.



a) *b*)

Figure 1 – Combustion chamber geometry (*a*) and finite difference mesh (*b*)

Table 1: Basic geometric parameters of the combustion chamber of the BKZ-75 boiler

Name	Symbol	Unit	Value
Height of the combustion chamber	H	m	16.75
Width of the combustion chamber	*b*	m	6
Depth of the combustion chamber	Γ	m	6.6
Frontal and posterior wall area	F_{fr}, F_p	m^2	90.675
Area of the right-side wall	F_{s_1}	m^2	92.4
Area of the left side wall	F_{s_2}	m^2	110.55
Top wall area	F_s	m^2	27.72
Bottom wall area	F_h	m^2	7.26

The cross-sectional area of the air channel burner	F_a	m^2	0.12
The cross-sectional area of the secondary air duct in the burner	F_{sa}	m^2	0.25

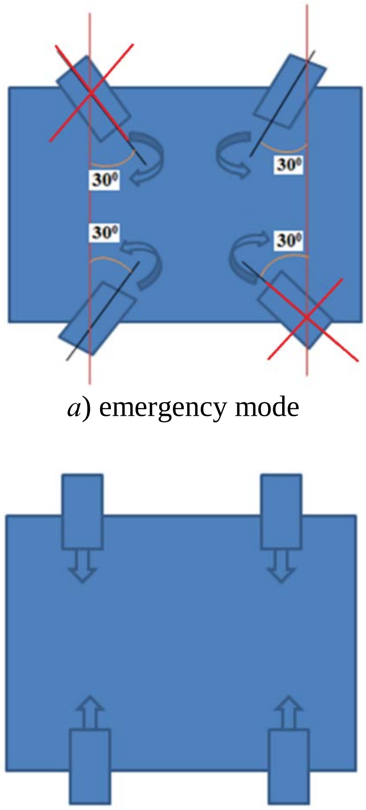
The German computer software system FLOREAN was used as a starting point for conducting computational experiments to explore the mechanisms of heat and mass transfer in the combustion chamber of a CHP boiler [10-12]. This software system enables complicated computational experiments on modeling reactive multiphase flows in different scenarios, and it is widely used in Germany to investigate heat and mass transfer processes in combustion chambers of numerous thermal power plants. Numerous computer studies on the combustion of pulverized coal fuel in the combustion chambers of thermal power plants in multiple countries were undertaken by German colleagues (Germany, England, Croatia, Greece, Romania, etc.). Full-scale tests carried out directly at running TPPs were used to successfully verify the achieved results.

We established an approach for utilizing the FLOREAN software system throughout the dissertation study. The reality is that Kazakh coal (with an ash concentration of up to 50%) differs greatly from German coal (with an ash level of roughly 8%), as do the geometry of domestic combustion chambers and the manner of providing fuel and oxidizer. We had to augment, expand, and test the FLOREAN start-up software system to undertake computational studies on the burning of high-ash Kazakh coal at Kazakhstan Republic TPPs.

In accordance with the given geometry of the BKZ-75 boiler, a finite-difference grid was created for numerical simulation, which for the studied combustion chamber BKZ-75 has steps along the X, Y, Z axes: 59×32×67, which is 138,355 control volumes (Figure 1). Calculations according to the numerical model are performed for the conditions adopted in the organization of a real technological process of fuel combustion at TPPs.

Computational studies were carried out to investigate alternative modes of feeding pulverized coal to the combustion chamber using computer modeling methods: 1) direct-flow technique of supplying air mixture - burners are located on opposite side walls (Figure 2b); 2) vortex technique of air mixture supply - only two vortex burners operate with the swirl angle of the air mixture flow and their inclination to the center of symmetry of the boiler by 30 degrees, and two are in emergency mode, out of four burners (Figure 2*a*).

The main aerodynamic parameters (velocity, pressure, kinetic energy of turbulence, and energy of dissipation) of the heat and mass transfer process in the combustion chamber in the volume of the combustion chamber and at the outlet were obtained using computer experiments.



a) emergency mode

b) basic mode

Figure 2 – Layout of burners of the combustion chamber

Physical and Mathematical Model

Physical-mathematical models used in this study include a system of three-dimensional Navies-Stokes equations, heat, and mass transfer equations, with source terms determined by the process's chemical kinetics, nonlinear effects of thermal radiation, interfacial interaction, and multi-stage chemical reactions. The basic equations used to solve the problem are [13-15].

The law of conservation of mass (continuity equation):

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x_i}(pu_i) = S_m. \quad (1)$$

The law of conservation of momentum (Navies-Stokes):

$$\frac{\partial}{\partial t}(pu_i) = -\frac{\partial}{\partial x_j}(pu_i u_j) + \frac{\partial \tau_{ij}}{\partial x_j} - \frac{\partial P}{\partial x_i} + pS_m, \quad (2)$$

where ρ is the density, u_i, u_j, are velocities in the directions i, j, x_i, x_j are Cartesian coordinates, τ_{ij} is the viscous stress tensor, P is the pressure, S_m is the interfacial interaction force.

The law of conservation of energy (the first law of thermodynamics):

$$\frac{\partial}{\partial t}(ph) = -\frac{\partial}{\partial x_i}(pu_i h) - \frac{\partial q_i^{res}}{\partial x_i} + \frac{\partial P}{\partial t} + \\ + u_i \frac{\partial P}{\partial x_i} + \tau_{ij}\frac{\partial u_j}{\partial x_i} + S_h, \quad (3)$$

where h is the specific enthalpy, q_i^{res} is associated with the energy transfer due to thermal conductivity of the substance flow and diffusion, S_h is the energy source due to chemical reactions and heat exchange by radiation.

The law of conservation of mixture components:

$$\frac{\partial}{\partial t}(pC_\beta) = -\frac{\partial}{\partial x_i}(pC_\beta u_i) + \frac{\partial j_i}{\partial x_i} + S_\beta, \quad (4)$$

where C_β is the mass concentration of β component β, j, i is the mass flow in the i -th direction, S_β is the source term of component β.

A system of turbulent transfer equations was utilized to calculate the aerodynamic properties, with the conventional k-turbulence model as the closure. This model has shown stability, efficiency, and fair accuracy in investigations of heat and mass transfer processes in turbulent reacting pulverized coal flows, making it ideal for solving industrial challenges. The standard k-ε model is represented by the turbulent kinetic energy transfer equation:

$$\frac{\partial(\rho k)}{\partial t} = -\frac{\partial(\rho u_j k)}{\partial x_j} + \\ + \frac{\partial}{\partial x_j}\left[\frac{\mu_{eff}}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + P - \rho \cdot \varepsilon, \quad (5)$$

and the dissipation equation (transformation of the kinetic energy of turbulence into internal energy) of turbulent kinetic energy ε:

$$\frac{\partial(\rho\varepsilon)}{\partial t} = -\frac{\partial(\rho u_j \varepsilon)}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\frac{\mu_{eff}}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + \\ + C_{\varepsilon,1} \cdot \frac{\varepsilon}{k} \cdot P - C_{\varepsilon,2} \cdot \frac{\varepsilon^2}{k} \cdot \rho. \quad (6)$$

The basic equations used in this work can be written in generalized form as follows:

$$\frac{\partial(p\phi)}{\partial t} = -\frac{\partial(pu_1\phi)}{\partial x_1} - \frac{\partial(pu_2\phi)}{\partial x_2} - \frac{\partial(pu_3\phi)}{\partial x_3} \\ + \frac{\partial}{\partial x_1}\left[\Gamma_\phi \frac{\partial \phi}{\partial x_1}\right] + \frac{\partial}{\partial x_2}\left[\Gamma_\phi \frac{\partial \phi}{\partial x_2}\right] \\ + \frac{\partial}{\partial x_3}\left[\Gamma_\phi \frac{\partial \phi}{\partial x_3}\right] + S_\phi$$

where ϕ is a transport variable; S_ϕ is the source term, which is influenced by the process' chemical kinetics, nonlinear thermal radiation effects, interphase interaction, and multi-stage chemical reactions. The above system of equations is solved numerically using the control volume method described in detail in and used in numerical computations of high-ash coal combustion in Kazakhstan's thermal power plants.

To solve the problem, the mathematical model should include specific initial and boundary conditions for desired functions (velocity, temperature, mixture component concentrations, and so on) that correspond to the geometry of the chosen combustion chamber and the real technological process of fuel combustion at TPPs.

Initial conditions: $u = 0$, $v = 0$, $w = 0$, $P = 0$, at $t = 0$.

The boundary conditions are set on the free surfaces, which are the burners, the exit from the furnace chamber of the boiler and the plane of symmetry.

Input: u_i are speed values, c_β is the initial concentration of each component, the enthalpy h is determined by the input flow temperature from the following relation:

$$C_P = \frac{\partial h}{\partial T} \quad (7)$$

where T is the temperature at the inlet (experiment or calculation).

Output: $\left.\frac{\partial u_i}{\partial x_i}\right|_{normalA} = 0$, $\left.\frac{\partial h}{\partial x_i}\right|_{normalA} = 0$, $\left.\frac{\partial c_\beta}{\partial x_i}\right|_{normalA} = 0$ are derivatives of velocity, enthalpy and concentration of components normal to the output plane.

In the plane of symmetry: $u_i|_{normalS} = 0$ is the velocity normal to the plane of symmetry, $\left.\frac{\partial u_i}{\partial x_i}\right|_{normalS} = 0$, $\left.\frac{\partial h}{\partial x_i}\right|_{normalS} = 0$, are the derivatives of velocity and enthalpy normal to the plane of symmetry, $\left.\frac{\partial h}{\partial x_i}\right|_{taS} = 0$ is the derivative of the enthalpy tangential to the plane of symmetry, $\left.\frac{\partial c_\beta}{\partial x_i}\right|_{normalS} = 0$ is the derivative of component concentrations normal to the plane of symmetry.

On the solid surface: $u_i|_{normalB} = 0$, $\frac{\partial u_i}{\partial x_i}\Big|_{normalB} = 0$, $u_i|_{taB} = 0$,$\partial p|_{boundary} = 0$ is the correction for pressure on the border of the solid surface, $\frac{\partial c_\beta}{\partial x_i}\Big|_{normalB} = 0$.

The boundary conditions for the temperature on the wall are determined by the convective heat flux $q_w = \alpha(T_{Steam} - T_{Surf})$. In case of variable temperature of the wall of the combustion chamber, the heat flux can be calculated by the formula:

$$\dot{q} = \underbrace{б(T_{FG} - T_{sufr})}_{convection} + \underbrace{C_{12}(T_{FG}^4 - T_{Surf}^4)}_{radiation}, \quad (8)$$

where $C_{12} = \varepsilon_{12}\sigma$, T_{FG} is the temperature of the flue gases, T_{Surf} is the surface temperature of the chamber wall, α is the coefficient of heat transfer by convection, W/(m^{2}K), ε_{12} is the emissivity wall, σ is the Boltzmann constant, W/(m^{2}K^4).

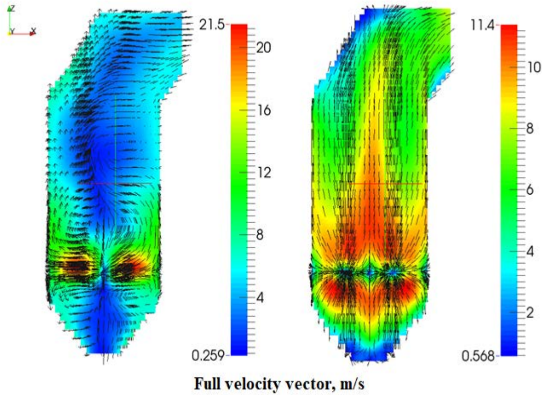
Results and Discussion

Figures 3 and 4 show the distributions of the full velocity vector $v = \sqrt{U^2 + V^2 + W^2}$ in its various sections of the combustion chamber of the BKZ-75 boiler. The full velocity vector is indicated in the figures as arrows of various colors. The direction of the arrow indicates the direction of the velocity of the medium, and using the color scale, you can determine its numerical value. The case under study (emergency mode of two burners) is compared with the base case (four once-through burners). The resulting fields of the total velocity vector make it possible to analyze the movement of reacting flows in the furnace space in its various sections, which are indicated here in the figures.

It should be emphasized that the numerical values are not equal. of the total velocity vector in both modes differ significantly. This is since when the boiler is operating in the basic mode, four burners are used, through which the aerosol mixture with the oxidizer is supplied, while in the emergency mode, only two burners operate, through which (to avoid a change in the excess air ratio and loss of total power) approximately the same amount of coal dust and air. Thus, with the same diameters of the burner channels, in an emergency mode, the amount of air mixture and oxidizer is involved with a high flow rate, respectively, and the velocity of their outflow will significantly increase.

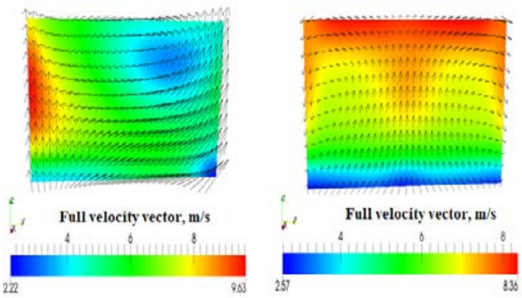
The residence period of coal particles in the middle of the combustion chamber rises in the presence of a vortex flow in the vertical plane. As a result, an increase in the flow rate has no discernible impact on the general organization of the boiler's emergency operation. As a result, at the combustion chamber's exit, we obtain a uniform flow with about the same velocity in both circumstances (Figure 4).

The aerodynamic picture shown in Figures 3 and 4 fully characterizes the behavior of the pulverized coal flow and corresponds to the actual physical processes occurring in the combustion chamber of the BKZ 75 boiler installed at the Shakhtinskaya TPP.



a) emergency mode *b*) basic mode

Figure 3 – Distribution of the total velocity vector in the central section (*y*=3.3 m) of the combustion chamber

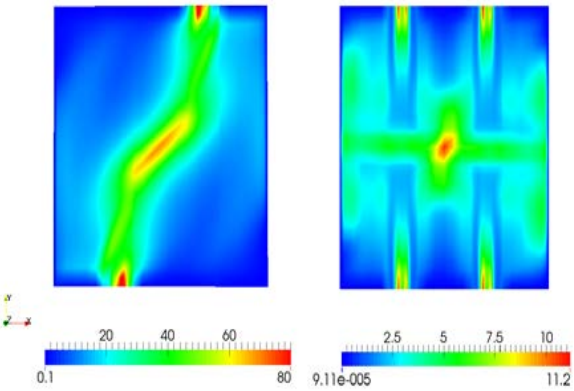


a) emergency mode *b*) basic mode

Figure 4 – Distribution of the total velocity vector at the exit from the combustion chamber

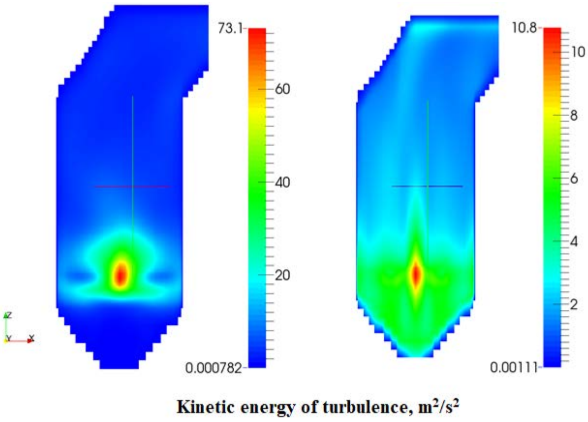
The distribution of the kinetic energy of turbulence in the main sections of the combustion chamber is shown in Figures 5 and 6. The vortex region with the greatest changes in velocity fluctuations, as well as the region with the most intensive processes of physical and chemical transformations of pulverized coal, is the area of installation of burners. In this part of the combustion chamber, the oxidation reactions of the fuel components proceed at the highest rate, as evidenced by the maxima in the distribution of the turbulent characteristics of the process.

Figures 7 and 8 depict the dissipation energy of kinetic energy of turbulence in the longitudinal portion of the BKZ-75 boiler's combustion chamber at Shakhtinskaya CHPP. It can be seen from the presented figures that the dissipation energy reaches its maximum values in the belt of burners at a height of 4 meters, since this area is a zone of collision of pulverized coal flows, which is caused by a non-stationary disturbance of the swirling flow and in which a sharp jump of turbulent pulsations is observed. The non-stationary disturbance of vortex flows has the greatest effect on the length of the torch, its emissivity, as well as on the intensity of heat and mass transfer processes during the combustion of pulverized coal in the combustion chamber. The described behavior of the total velocity vector is also consistent with the pressure distribution in the combustion chamber.



a) emergency mode *b*) basic mode

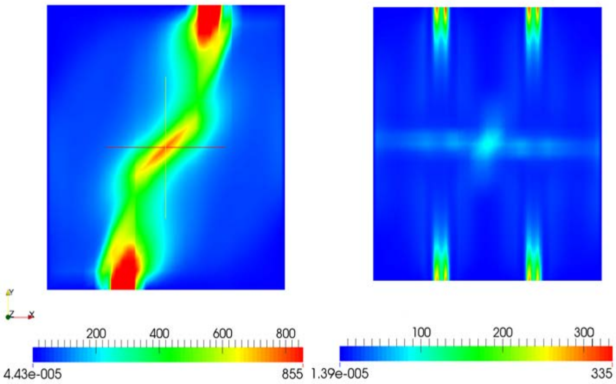
Figure 5 - Distribution of the kinetic energy of turbulence in the cross section of the burners of the combustion chamber BKZ-75 of the Shakhtinskaya TPP



a) emergency mode *b*) basic mode

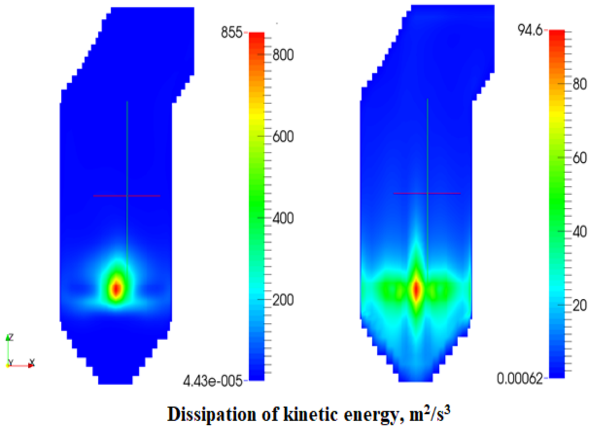
Figure 6 – Distribution of kinetic energy of turbulence in the central section (y=3.3 m) of the combustion chamber

The three-dimensional pressure field in the longitudinal sections of the combustion chamber is shown in Figures 9 and 10. An analysis of the figure shows that the pressure decreases along the height of the combustion chamber. In addition, a pronounced minimum is observed in the area where the burners are installed. This is explained by the fact that in this area there is an interaction of two oppositely directed flows of pulverized coal, which, penetrating each other, create a rarefaction in the combustion chamber. Further, the pressure continues to decrease with the height of the combustion chamber up to the section of the rotary chamber of the boiler, where, due to a change in the geometry of the combustion chamber, the air flows are redistributed and the pressure at the outlet of the combustion chamber is 7 Pa.



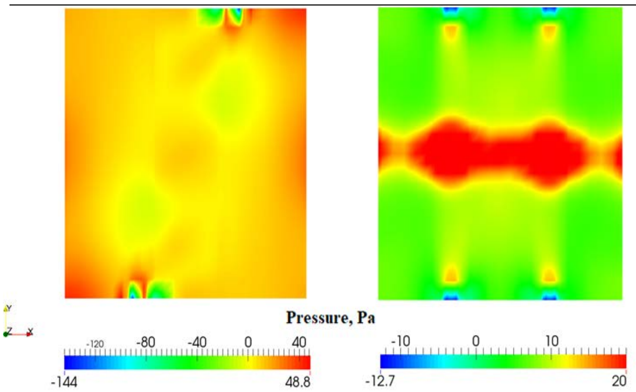
a) emergency mode *b*) basic mode

Figure 7 - Distribution of dissipation energy in the cross section of the installation of burner devices of the combustion chamber



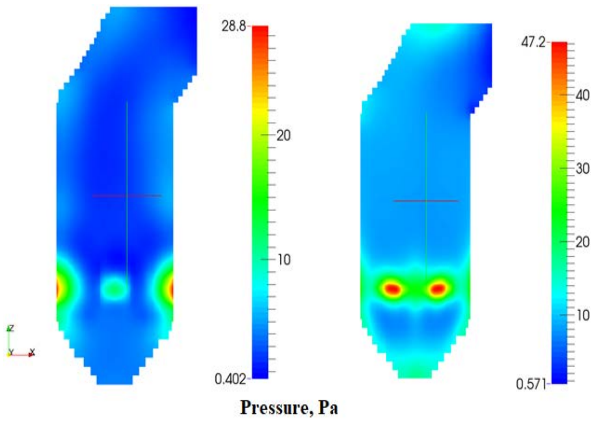
a) emergency mode *b*) basic mode

Figure 8 - Distribution of dissipation energy in the central section (y=3.3 m) of the combustion chamber



a) emergency mode *b*) basic mode

Figure 9 - Pressure fields in the burner section



a) emergency mode *b*) basic mode

Figure 10 - Pressure fields in the central section (y=3.3 m) of the combustion chamber

Conclusion

The aerodynamic properties established during the computer experiment are representative of the genuine technical process seen in the combustion chambers of running TPP boilers. The above results show that there is a sharp change in the aerodynamic characteristics of the process (velocity, pressure, kinetic energy of turbulence k, energy of dissipation ε) in the central region of the combustion chamber, with the formation of a vortex flow, which weakens as the combustion products move towards the combustion space's exit area.

The presence of a vortex motion allows the flame to ignite and stabilize more quickly. Hot gases are pulled into the torch, where they heat the combustible mixture and increase the ignition intensity. Active ascending fluxes are also present along the furnace's walls, which influences the convective component of heat transmission in the combustion chamber. Greater flame ignition at the burner's outlet is caused by the vortex nature of the flow movement inside the combustion chamber, and increased heat and mass transfer in the vortex worsens burnout.

At the same time, it is feasible to produce consistent heating of the combustion chamber surfaces and decrease slagging, extending the equipment's life. Due to the circulation of particles in the vortex flame, combustion proceeds with sufficient completeness, even with coarse grinding, which makes it possible to significantly expand the range of coal dust used. The study findings will enable effective control of fuel combustion processes in real power plants with the required impact on various parameters, as well as finding the best burner design solutions, developing optimal methods for burning high-ash coal, and reducing harmful dust and gas emissions into the atmosphere, all of which will undoubtedly contribute to solving urgent problems in thermal power engineering.

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