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3-D Modeling of Heat and Mass Transfer during Combustion of Solid Fuel in Bkz-420-140-7C Combustion Chamber of Kazkhstan

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ABSTRACT

In this paper the results obtained by the numerical method of modeling of Ekibastuz coal burning in BKZ-420 combustion chamber of Kazakhstan Power Plant are presented. They are devoted to the numerical simulation of combustion processes in the furnace boiler BKZ-420. Boiler's steam generates capacity equal 420 T/h. Boiler has six vertical pulverized coal burners arranged in two levels with three burners on the front wall of the boiler. High ash, low-grade coal from Ekibastuz burned in the furnace. Its ash content is 40%, volatile – 24%, humidity–5%, highest calorific value is 16750 kJ/kg. Milling dispersity of coal was equal to R_{90} = 15%.It was shown in this research that the most intense burning is observed in the central part of the chamber where the flow temperature reaches about 980 °C and it is seen that the temperature reaches a peak in the cross sections of the burners location. The combustion reaction there occurs more intensively.

Keywords: BKZ-420; Combustion; Ekibastuz coal; Heat and mass transfer; Modeling; Pulverized coal; Turbulence; Two–phase flow.

1. INTRODUCTION

The study of convective heat problems in turbulent flows in the presence of chemical reactions is an important task of thermal physics and hydrodynamics; as such, flows are widespread in nature and play an important role in many technical devices. Knowledge of the laws of such flows is important in constructing a theory of physics of combustion, creating a new physical-chemical technology, as well as problem solving in power engineering and ecology. In complex studies of the combustion process it should be analyzed depending on the influence of numerous physical and chemical parameters of the combustion reaction (El-Mahallawy *et al.* 2002). The development of theory of heat and mass transfer, improvement on this basis manufacturing processes and systems with the rational use of energy resources is an actual task.

At the moment the world energy in the foreseeable future based on the use of fossil fuels, mainly low-grade coal. It should be noted that the deterioration of steam coal is widespread, and not only in the CIS countries, but also in the developed capitalist countries. Today the world's thermal power plants (TPP) produce more than 40% of electricity and heat. Although generally coal had several 'ups and downs' during its utilization history, it is still one of the most important fuels for generation of primary energy, especially of electric energy (Fig.1). According to International energy Agency (IEA) statistics issued in 2003, coal supplies around 24% of primary energy needs and generates some 40% of produced global electricity, while further increase in utilization of coal is expected in the future (Review of International Energy Agency 2003).

Energy Industry of Kazakhstan Republic is aimed at the use of coal as an energy fuel. According to the «Statistical Review of World Energy» (Statistical Review of World Energy), prepared by the British company, at the beginning of 2013, Kazakhstan is one of the leading countries in coal reserves, only after China, USA, Russia, Australia, South Africa and India and ranked 8th place that divides our country with Ukraine (Statistical Review of World Energy 2003). Kazakhstan holds about 3.9% of global coal reserves. Today in Kazakhstan coal reserves constitute 33.6 billion tons. Ekibastuz coal field is the main source of raw materials to be used in the energy industry due to obtaining it by open way. But because of the characteristics of this fuel and its special importance, it is got to fundamental researches with practical relevance and aimed at improving the combustion efficiency of energy consumption and minimize emissions of harmful dust and gas emissions in Kazakhstan.

Currently in Kazakhstan, about 85% of electricity is produced by thermal power plants (TPP), the main fuel is coal. More than 80% of coal burned at thermal power plants is the low grade and the ash content is of approximately 50%.

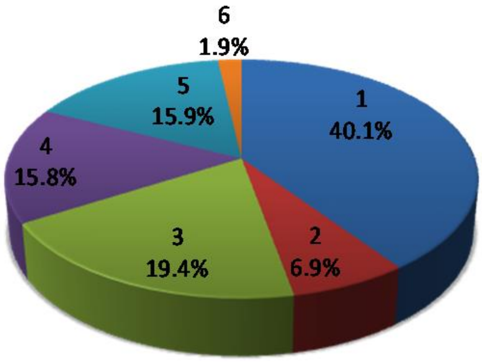


Fig. 1. Total world electricity generation by fuel. (1)coal, (2) – liquid fuel (fuel oil, diesel fuel), (3) – gas, (4) – nuclear energy, (5) – hydro, (6) – other (solar, wind, geothermal, waste, including vegetable origin).

The main area of improvement of coal combustion and the use of alternative fuels is the implementation of stringent environmental requirements on specific emissions of harmful substances with waste gases of boiler plants. And at this point, the technologies, allowing to describe the main processes of the formation of harmful dust and gas emissions, development of recommendations on their mitigation and the search for more efficient methods of coal burning is the urgent task for researchers.

Investigation of turbulent combustion of solid fuels, coal-fired and problem solving of modern thermal physics, power engineering and ecology is the urgent need not only for our country, but also a problem of global proportions. This is evidenced by similar studies that are conducted in the CIS countries, the European Union and the United States (Mitchell and Tarbell 1982; Smoot 1981; Lewis and Smoot 1981; Zadghaffari *et al*. 2012).

Solution of many technical tasks is impossible without using of CFD software packages (Fluent 2006; Moyeda *et al*. 2001), allows modeling of difficult particular process in practice. In this article the numerical study of physical characteristics and aerodynamic properties of pulverized fuel combustion in thermal power plant with FLOREAN program complex (Askarova *et al.* 2009) was investigated.

Investigation of problems of convective heat and turbulent flows in the presence of chemical reactions is an actual problem of thermo-physics and hydroaerodynamics, because such flows are widely distributed in nature and take importance in many technical devices. Knowledge of laws of such flows is important when constructing combustion physics theory, at creation new physical-chemical technologies, and also at the decision of problems of power system. In our researches the difficult combustion process should be analyzed according to the influence of physical and chemical parameters to the combustion reaction.

For the research of physical and chemical processes in combustion chambers we used numerical methods of burning, which are the main components of computational hydrodynamics. With the help of the software package FLOREAN we got the velocity, temperature and reaction products fields of heat and mass transfer processes, the latter in turn have been processed using the numeric base PARAVIEW in the form of diagrams.

2. PHYSICAL FORMULATION OF THE PROBLEM

2.1 Physical Model

The model presented in to the numerical simulation of BKZ-420 combustion chamber. Its steam capacity equal to 420 T/h. Boiler equipped with six vortex dust burner, arranged in two levels with three burners on the front wall of the boiler as shown in Figure 1. Low-grade high-ash coal dust from Ekibastuz has burnt in the boiler, it has ash content of 40 %, volatile – 24 %, moisture content – 5 % and the highest calorific value 16700 kJ/kg (see Table I). The fineness of coal milling is equal to R_{90} = 15 %. All numerical calculations were performed on above characteristics.

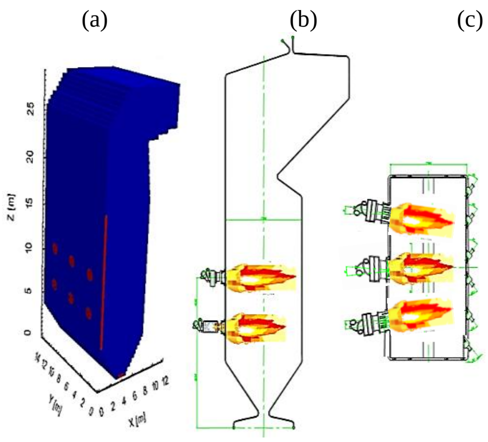


Fig. 2. General view of the industrial boiler BKZ-420 of the Almaty TPP-2. (a)3D view of BKZ-420 boiler and its breakdown into control volumes; (b) burners establish arranged on two levels; (c) top view on the cross section (h = 10.75m).

On the front wall of the combustion chamber six double-flow vortex of dust and gas burners in two stages (three per stage) are established. The last burner turned to the center of burner by 8 degrees. The capacity of each burner is 12 T/h (Fig.2). Industrial implementation of any new technology is not possible without preliminary analysis of advantages and disadvantages of the suggested method. The rapid development in computer sciences gives the advance to computational techniques to be used for simulation of complex combustion processes in industrial furnaces.

Table 1 Source data of coal and BKZ-420 combustion chamber for numerical calculation

Characteristic	Quantity
Coal type	Ekibastuz
Density of particles	1300 kg/m³
C_{daf}, %	82.0
H_{daf}, %	5.0
N_{daf}, %	1.5
O_{daf}, %	11.5
Ash , %	40.0
Humidity , %	5.0
Volatile content, %	24-28
Coal consumption in the boiler	72 000 kg/h
Consumption of coal to the burner through two channels	12 000 kg/h
Primary air flow to the boiler	107 035 kg/h
Secondary air flow rate to the boiler	402 656 kg/h
The temperature the secondary air	280 ºC
Temperature of aeromixture	88.85 ºC
The average particle size of coal	64 mcm
The lower heating value of coal	16 750 kJ/kg
The amount of computation (control volumes)	671 113

Products of combustion contain different harmful substances and the emission of these components grows into a great problem. Industrial development causes an increase in hydro carbonaceous fuels' consumption. These fuels contain harmful and poisonous components such as carbonic oxide (CO), nitric oxide (NO), sulfur dioxide, acid sulfate, lead combinations and different hydrocarbons, etc.

Table 2 Characteristics of coal

EKIBASTUZ COAL	
Structure and its characteristics	Structure (%)
W	8.0
A	36.8
S	0.8
C	44.2
H	2.9
O	6.5
N	0.8
V	30
$Q^{P}_{H}/10^4$ (kJ/кg)	1.697

In this paper software package FLOREAN (Launder and Spalding 1974; Leithner and Müller 2003) for 3D modeling of coal-dust combustion in furnaces of real-sized boilers was used. This program enables to calculate velocity components *u*, *v*, *w*, temperature *T*, pressure *P*, concentration of combustion products and other turbulence characteristics of combustion process all over the combustion space and at its exit. Pressure is determined through the connection between the continuity equation and the equation of motion by means of Patankar's Simple-method (Patankar 1980).

Complex physical and chemical processes include the conservation equations of mass, conservation of angular momentum and energy for the gas and solid phases. The gas flow is considered in the Euler system, the dynamics of a solid phase is considered in the Lagrangian system. The turbulent structure of the flow is described by a two-parameter model of turbulence. The radiation heat transfer is determined on six stream model.

To decrease emissions of harmful substances various methods are applied, including special fire regimes (organization of combustion process),which suppresses the formation of harmful substances in flame and two-stage burning, when the burners work with low air surplus. In this way numerical experiments became one of the most effective and suitable means for detail analysis and in-depth study of physical and chemical phenomena.

The mathematical description of the physical and chemical processes are based on the solution of the balance equation. In general, all of these equations contain four components:changes in the value of time, component describing convective transport, component describing diffusive transport, component describing the source or flow.

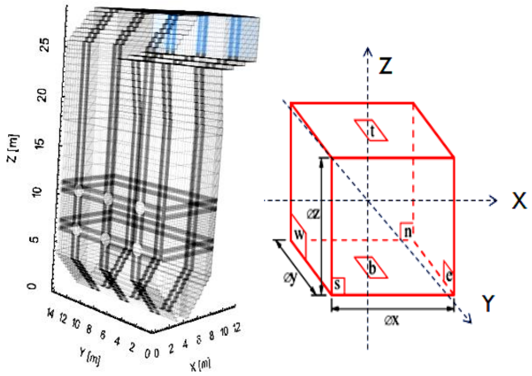


Fig. 3. The scheme of the boiler separated with control volume and elementary control cell.

2.2 Mathematical Model

Among the methods of modeling the combustion of pulverized fuel most widely used method is based on the Euler, an approach to describe the motion and heat transfer of the gas phase. This method uses the spatial balance equations for mass, momentum, the concentrations of gaseous components and energies for the gas mixture. To describe the motion of single particles and heat mass transfer of fuel along their trajectories we used Lagrange approach. Turbulent flow structure is described by a two-parameter *k-ε* model of turbulence, where *k*–the kinetic energy of turbulence, *ε*–turbulent energy of dissipation.

The mathematical description of physical and chemical processes based on the solution of balance equations. In general, these equations contain four terms describing:

- change in the value of time;

- convective transfer;
- diffusive transfer;
- source or sink.

In figure shown generalized model of control volume 4, where $\rho u\phi|_{i,i+\Delta i}$ – describes the convective transfer across the borders of the variable control volume in Cartesian coordinates. To derive the balance ratios we selected stationary control volume element or control element of mass (Fig. 4). It is supposed that the center of gravity of the selected element moves with the velocity of flow. This corresponds to a stationary control volume sound approach for the Euler flow. Change the value of the transport is described in a single fluid element. The value of this quantity determined at each point of the domain.

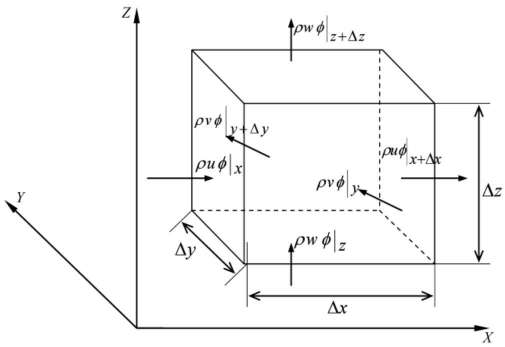


Fig. 4. Control volume for the generalized transport equation.

By converting from a finite limit to the infinitesimal volume element obtained by controlling the differential equation describing the conservation of the transport variable ϕ :

$$\frac{\partial(\rho\phi)}{\partial t} = -\frac{\partial(\rho u_1\phi)}{\partial x_1} - \frac{\partial(\rho u_2\phi)}{\partial x_2} - \frac{\partial(\rho u_3\phi)}{\partial x_3} + \frac{\partial}{\partial x_1}\left[\Gamma_\phi \frac{\partial\phi}{\partial x_1}\right] + \frac{\partial}{\partial x_2}\left[\Gamma_\phi \frac{\partial\phi}{\partial x_2}\right] + \frac{\partial}{\partial x_3}\left[\Gamma_\phi \frac{\partial\phi}{\partial x_3}\right] + S_\phi \tag{1}$$

where, ρ – density; u_i – flow speed in the direction x, y, z; ϕ – variable transfer, Γ – diffusion coefficient.

Changing in eq. (1) the convective and diffusive transfer of flux density, cross-border control volume, we obtain a flux density:

$\Phi_{(K),j} = \rho u_j\phi$ – convective component,

$\Phi_{(D),j} = \Gamma_\phi \dfrac{\partial\phi}{\partial x_j}$ – diffusive component.

Then, taking into account eq. (1), written as:

$$\frac{\partial(\rho\phi)}{\partial t} = -\frac{\partial\Phi_{(K),j}}{\partial x_j} + \frac{\partial\Phi_{(K),j}}{\partial x_j} + S_\phi \tag{2}$$

We write eq. (2) in vector form:

$$\frac{\partial(\rho\phi)}{\partial t} = \mathrm{div}\left((-\rho u\phi) + \Gamma_\phi \mathrm{grad}\phi\right) + S_\phi,$$

and in tensor form, equation (2) takes the form:

$$\frac{\partial(\rho\phi)}{\partial t} = -\frac{\partial(\rho u_j\phi)}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\Gamma_\phi \frac{\partial\phi}{\partial x_j}\right] + S_\phi \tag{3}$$

To calculate the gas flow solid-phase with the input of all transport quantities in the control volume are determined by the generalized equation (3). In this equation S_ϕ – is source (sink) term for the quantity ϕ, other terms describes the variation of ϕ :

$\dfrac{\partial(\rho\phi)}{\partial\tau}$ – time component,

$\dfrac{\partial(\rho u_j\phi)}{\partial x_j}$ – convective transfer,

$\dfrac{\partial}{\partial x_j}\left[\Gamma_\phi \dfrac{\partial\Phi}{\partial x_j}\right]$ – molecular transfer.

In mathematical model of gas, flow or liquids the equations of conservation of mass and momentum were used. For flows in which the processes of heat transfer are taken place, as well as for compressible media we have to solve the equation of energy conservation. In flows with the processes of mixing of different components, with the reactions of combustion, etc. it must be added the equation of conservation of the mixture components or the conservation equation for mixture fraction and its changes. For turbulent flow the system of equations is complemented by transport equations for turbulent characteristics.

Thus, to solve this problem we consider the equations describing the flow and which are derived from the generalized equation (3). This system has no analytical solution and can only be solved by numerical methods.

In general, for numerical solution the whole computational domain is divided into discrete difference grid point, or volume, continuous field variables is replaced by discrete values at the nodes of the grid, and derivatives in the differential equations are replaced by their approximate expressions in terms of the difference of function values at grid points. In the present study the problem is solved using the method of control volume. The system of algebraic equations for the differential equation of control volume for each balanced value is as follows:

$$a_P\phi_P = \sum_n a_n\phi_n + S_\phi \quad .$$

Coefficients are determining from the contribution of convective and diffusive flow in all directions at each point of control volume. As a result of approximation of equation (2) the algebraic equation was obtained (3) for each control volume and for each unknown variable ϕ_n. For each cell in the computational domain we used physical laws of conservation and differential equations describing these laws (transfer equation), integrated over the volume of each cell.

FLOREAN is based on the numerical solution of the Reynolds averaged balance equations for mass, species, energy and momentum. It predicts gas flows, species concentrations, temperature fields due to combustion, radiation and convective heat transfer and the pollutant formation and destruction in furnace chambers. The mean flow equations are investigated by the *k-ε* turbulence model.

The changes of the concentrations of flue gas components and the fuel due to the combustion are taken into account in the source sink terms by appropriate sub models.

In addition, in the source sink term the heat balance takes into account the energy release due to the combustion reactions and the significant heat transfer due to radiation using a six flux radiation model. Equation for conservation of thermal energy is written in terms of the enthalpy *h*. Radiation heat transfer is determined by 6 flux radiation models by Lockwood, etc. (Lockwood and Gossman 1973).

Pulverized coal flames are turbulent reacting two-phase flows. Particle presence is approximated as continuum and the mean particle velocity is assumed to be approximately equal to the gas phase velocity.

In the standard *k-ε* model we wrote basic transport equation of turbulent kinetic energy *k*:

$$\frac{\partial(\bar{\rho}k)}{\partial t} = -\frac{\partial(\bar{\rho}\,\bar{u}_j k)}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\frac{\mu_{eff}}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + P - \bar{\rho}\cdot\varepsilon \qquad (4)$$

where P - production of turbulent kinetic energy, which is defined by the following equation:

$$P = \left[\mu_{turb}\cdot\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \frac{2}{3}\cdot\rho\cdot k\cdot\delta_{ij}\right]\cdot\frac{\partial \bar{u}_i}{\partial x_j} \qquad (5)$$

The equation for the turbulent kinetic energy dissipation *ε* was written as:

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

The turbulent viscosity is determined by the equation of Prandtl - Kolmogorov:

$$\mu_t = C_\mu\cdot\rho\cdot\frac{k^2}{\varepsilon} \quad .$$

Where these are empirical constants: C_μ = 0.09; σ_k = 1.00; σ_ε = 1.30; $C_{1\varepsilon}$ = 1.44; $C_{2\varepsilon}$ = 1.92.

The boundary conditions for the turbulence model are defined as follows (kinetic energy of turbulence at the inlet):

$$k_{in} = 1.5(u_{i,in}Tu)^2$$

$$\frac{\partial}{\partial t}(\rho u_i) = -\frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial}{\partial x_j}(\tau_{i,j}) - \frac{\partial p}{\partial x_j} + \rho f_i \qquad (7)$$

where f_i –body forces; $\tau_{i,j}$ – the stress tensor. We define the initial and boundary conditions for the task.

For velocity:

$\frac{\partial u_i}{\partial x_i}|_{normA} = 0$ – derivative of the normal to exit plane;

$u_i|_{normS} = 0$ – velocity of normal to the plane of symmetry;

$\frac{\partial u_i}{\partial x_i}|_{normS} = 0$ – derivative of normal to the plane of symmetry;

$u_i|_{normW} = 0$ – velocity of the normal to wall, i.e. no mass flux;

$\frac{\partial u_i}{\partial x_i}|_{normW} = 0$ – derivative of the normal to walls;

$u_i|_{tang} = 0$ – velocity of the tangential to walls slip condition.

It should be noted that the modeling of flows in the presence of turbulence, which are taken as a basis for solving the equations for the turbulent characteristics (kinetic energy of turbulence and its dissipation), allows to obtain the desired accuracy of the solution, while excluding non-useful machine costs associated with obtaining it.

3. RESULTS AND DISCUSSION

The present paper provides an overview of the current capabilities of the CFD-computer code FLOREAN (acronym for FLOw and REActioN) developed at the Institute for Fuel and Heat Technology in Technical University of Braunschweig (Germany) and Al-Farabi Kazakh National University (Kazakhstan) (Askarova, Safarik, *et al.* 2015; Askarova, Bolegenova, *et al.* 2014; Askarova, Bekmukhamet, *et al.* 2014;

Askarova, Ospanova, *et al.* 2014; Askarova, Messerle, *et al.* 2014; Askarova, Karpenko, *et al.* 2006).

Simulation tool FLOREAN allows getting detailed information about furnace performance including velocities, temperature, thermal radiation and concentration distributions, etc. within the furnace and along the walls. The efficient combustion of solid fuel in combustion chambers and the efficient heat transfer to water and steam in steam generators are essential for the economical operation of power plants. This information is useful to evaluate the combustion process and to design optimal furnaces. FLOREAN will also be very useful in improving combustion process of different fuels in industrial boilers, optimizing operation and minimizing pollutant emission (Askarova, Bolegenova, *et al.* 2013; Askarova, Maximov, *et al.* 2012; Askarova, Lavrichsheva, *et al.* 2007).

Consequently, the FLOREAN – code was used to predict thermal and hydrodynamic aspects of flue gases mixing in the near wall region and inside the furnace. In the case of Over Fire Air (OFA) technology of simulations show that effective mixing between flue gases and over-fire air is of essential importance for CO re-burning and low NO_x emissions.

Florean solves a number of transport equations depending on the user's specific problem setup. It's given the (general) continuity, momentum, energy species and turbulence equations. Figures below shows the vector field full speed $V=\sqrt{u^2+v^2+w^2}$ throughout the volume of the combustion chamber by means of which one can characterize the behavior of pulverized coal flow within the combustion chamber. One can clearly see the area of the fuel mixture through the burner.

Fig. 5-7 shows the distribution of the velocity vector direction of the *x* axis height of the combustion chamber of the boiler BKZ-420, there we can see two peaks, its mean that speed of pulverized coal particles is *max* on the inlet of burner.

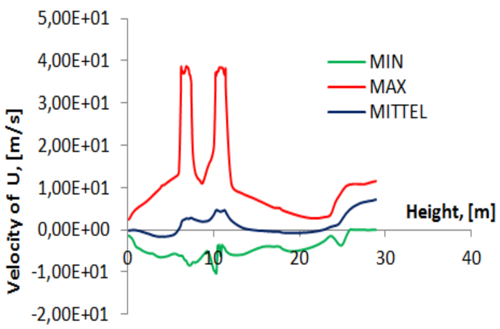


Fig. 5. Distribution of the velocity vector direction of the *x* axis height of the combustion chamber of the boiler BKZ-420-140-7C.

In Figure 8in the cross section, which accounts for the lower tier of burners (K=47, h = 10.75m) has *max* speed on the inlet, it equals to 40 m/s. Injection velocity of pulverized coal from two burners on two edges are maximum in comparison with the torches in the central part. As the velocity increasing, the pressure in this area is reduced, so the particles have mixed intensively, that is the turbulence increases. This picture of stream can be seen on Fig.11 (a).

Figure 9 shows the velocity profile on the cross section of the combustion chamber of the boiler BKZ-420 (J=132, Y = 7.2 m) by *Z* axis. There *max* speed equals to *W*=11 m/s.

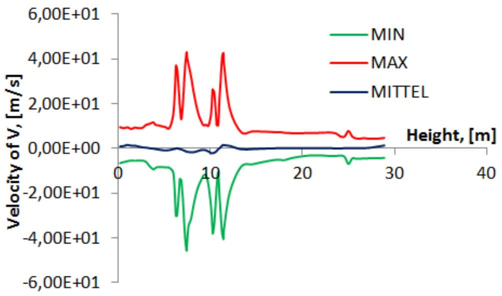


Fig. 6. Distribution of the velocity vector direction of the y axis height of the combustion chamber of the boiler BKZ-420.

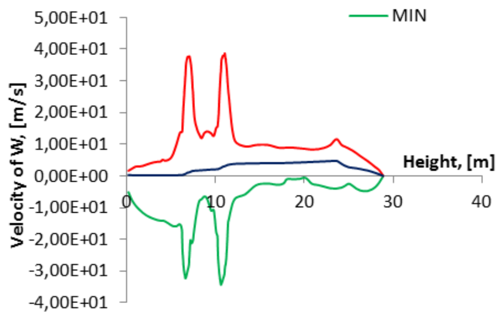


Fig. 7. Distribution of the vector velocity direction of the Z axis height of the combustion chamber of the boiler BKZ-420.

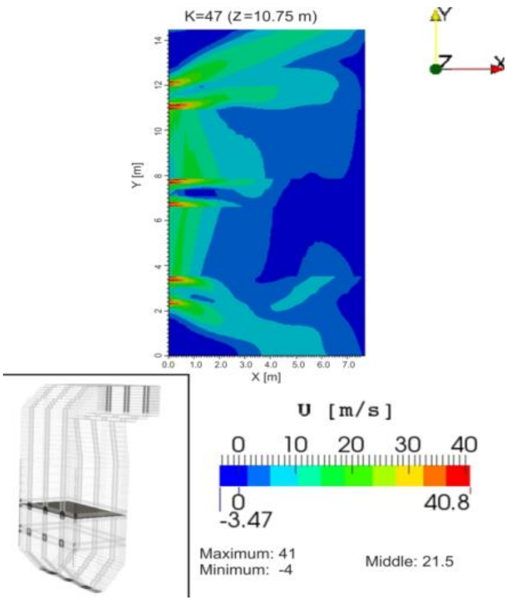


Fig. 8. Velocity profile on the cross section of the combustion chamber of the boiler BKZ-420 (K=47, Z = 10.75m).

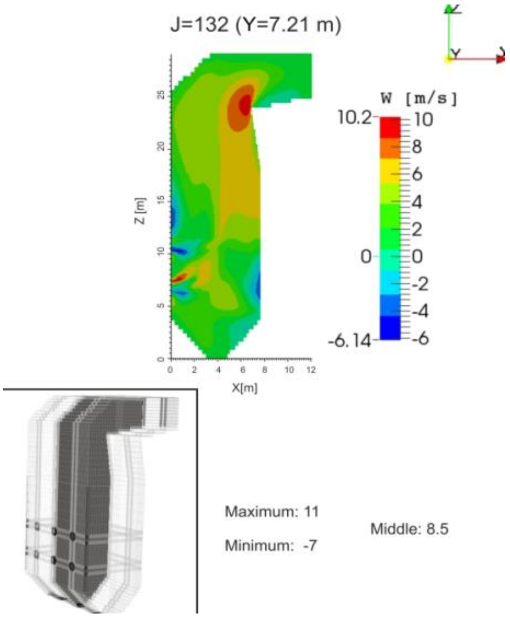


Fig. 9. Velocity profile on the cross section of the combustion chamber of the boiler BKZ-420 (J=132, Y = 10.75m).

Speed vector fields in the fig. 9 is shown as arrows vectors of length gives a value of full speed, their direction connected with the direction of the full-speed at the selected point of the combustion chamber. Presented on Fig. 10 model able to obtain whole velocity profile in the BKZ-420 chamber including three different levels by Y axis: Y_1 = 2.85 m, Y_2 = 7.2 m, Y_3 = 11.69 m.

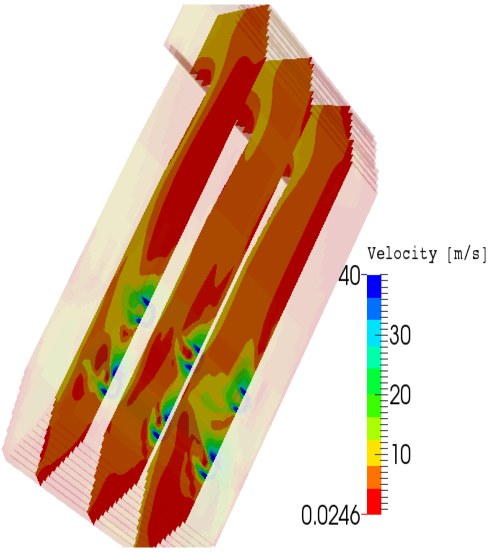
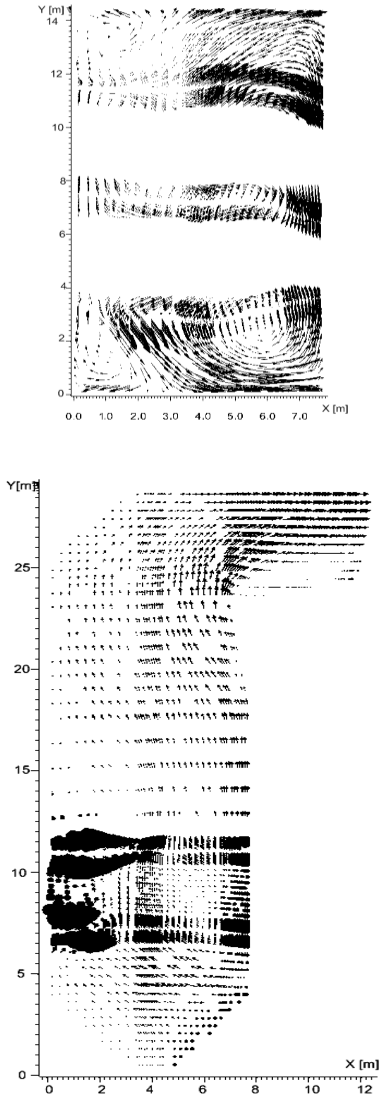


Fig. 10. Velocity profile on the different levels of the combustion chamber Y_1 = 2.85 m, Y_2 = 7.2 m, Y_3 = 11.69 m on the Y axis for two layers (z_1 = 6.2 m) and (z_2 = 10.75 m).

Fig. 11 illustrates the velocity distribution in the combustion chamber by means of which one can characterize the behavior of pulverized coal flow within the combustion chamber. One can clearly see the area of the fuel mixture through the burner. According to all of the figures above we can see *max* velocity on the inlet of burner, also on the cross section by Z axis (Z_2=6.2 m). Right and left sides of burner exist turbulence flow of combustion.

a)



b)

Fig. 11. Velocity vector profile by the height of combustion chamber: (a)Z_1=6.2 m, (b)Y=7.2 m.

On the basis of mathematical models and 3D computer modeling we had conducted the study of complex heat exchange processes taking place during combustion of low-grade coal fuel (Ekibastuz coal) on real energetic facility of the Republic of Kazakhstan (the combustion chamber of the boiler BKZ-420 of TPP-2). It is shown that the most intense burning is observed in the central part of the chamber where the flow temperature reaches about 980 °C. Due to the fact that coal particles in this area have a more intense radiation and have higher concentration and the total surface, it is seen that the temperature reaches a peak in the cross sections of the location of the burners. This is an area where combustion reaction occurs more intensively. As you approach the exit from the combustion chamber temperature profile is stabilized, and the differences between the minimum and maximum values decreases. Pressure field on the fig. 12 shows that maximum pressure on the below opposite side of burner.

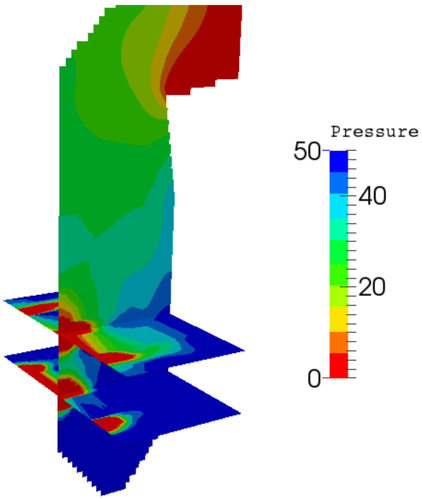


Fig. 12. Pressure profile by the height of combustion chamber.

As seen in Fig. 13, the temperature at the outlet of the combustion chamber is more than 1000 ^{0}C. The temperature values in the upper and lower tiers are much smaller. One reason for this - the fuel supplied to the furnace and the air that it contains interact with each other not immediately, as the process is slow. Consequently, the torch on the flame front burns intensely at 3-7 meters.

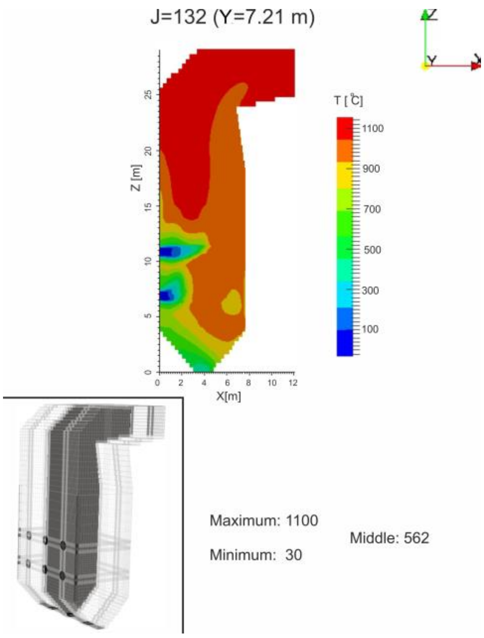


Fig. 13. Temperature distribution in the longitudinal section (y = 7.21 m) of the combustion chamber of the boiler BKZ-420,

As seen from Fig. 14 while coal is burning four torch are forming in the central area of the combustion chamber the common core with temperature of about 1100°C, because coal particles in this region have more intense radiation and have a higher concentration, and the total surface. Reflected in the figures information corresponds to the real picture of the process in the combustion chamber BKZ-420, Almaty CHP-2.

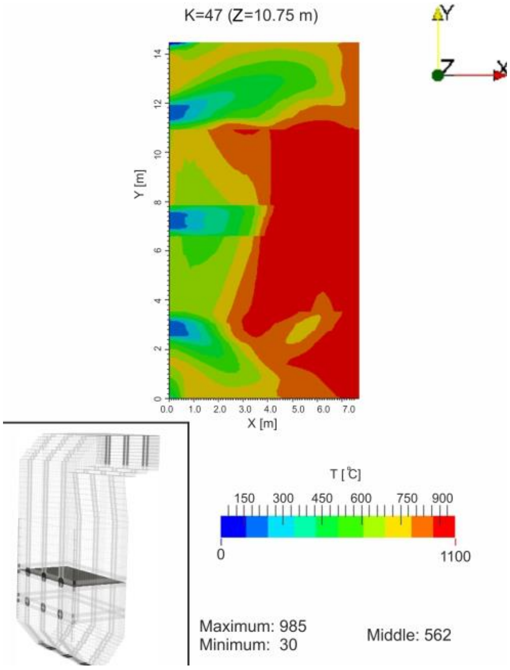


Fig. 14. Temperature distribution in the cross section (z = 10.75 m) of the upper tier of the combustion chamber of the boiler BKZ-420.

Analysis of Fig. 15-16 shows that the maximum carbon monoxide CO takes 3·10-3 kg/kg. In the field of burner CO concentration is set to equal $1.7\cdot10^{-3}$ kg/kg. As we move toward the exit of the combustion chamber CO concentration falls, since that decreases the concentration of carbon and oxygen, meaning it here $1.5\cdot10^{-3}$ kg/kg, and through a chemical reaction of CO reacts with oxygen oxidizes and forms CO_2.

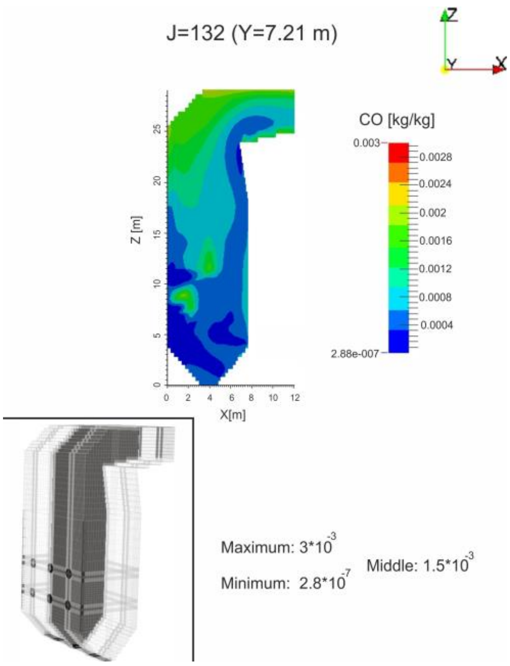


Fig. 15. Distribution of the concentration of CO in the longitudinal section (y = 7.21 m) of the combustion chamber of the boiler BKZ-420.

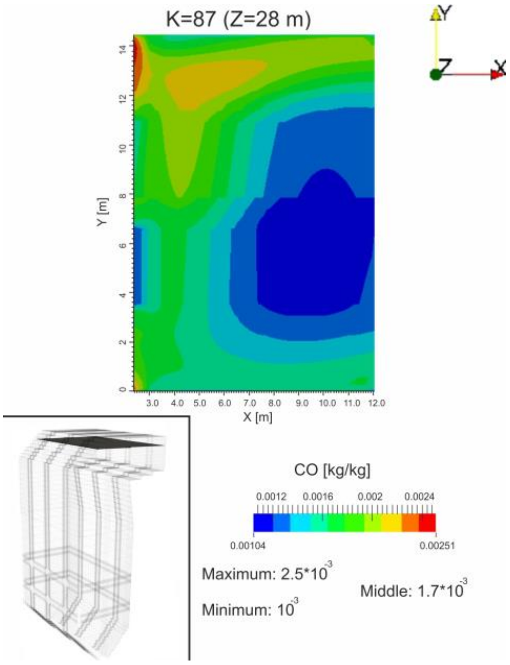


Fig. 16. Distribution of CO concentration at the outlet (z = 28 m) from the furnace combustion boiler BKZ-420.

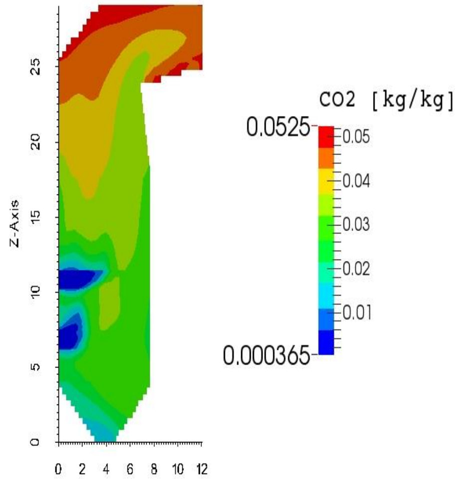


Fig. 17. Distribution of the concentration of CO_2 in the longitudinal section (y = 7.21 m) of the combustion chamber of the boiler BKZ-420.

The Figures 17-18 shows that the maximum carbon dioxide CO_2 takes 0.07 kg/kg. In the field of burner CO concentration is set to equal 0.009 kg/kg. As we move toward the exit of the combustion chamber CO_2 concentration falls, since that decreases the concentration of carbon and oxygen, meaning it here 0.04 kg/kg, and through a chemical reaction of CO reacts with oxygen oxidizes and forms CO2. These values correspond to the experimental data on the combustion of Ekibastuz coal (Messerle *et al.* 2010).

Fig. 19 shows the distribution of NO concentrations in height of the combustion chamber in the longitudinal section of the boiler. As can be seen from the figure, at the combustor inlet the concentration of nitric oxide is a maximum and equal to 0.0045 mg/Nm3. At the output of the boiler due to the thermo-chemical reaction NO concentration decreases and it is equal to 0.00012 mg/Nm^3. And in Figure 20 can be seen distribution of NO concentration by longitudinal section at a height of Z = 28m. Here, the maximum concentration of nitric oxide is 5,510^{-4} mg/Nm^3. At this stage of high ash coal combustion the development of heat and mass transfer description technology, the development of recommendations for reducing emissions and finding the best options of burning solid fuel are the urgent problem for researchers which are specializing in the field of power energy of Kazakhstan.

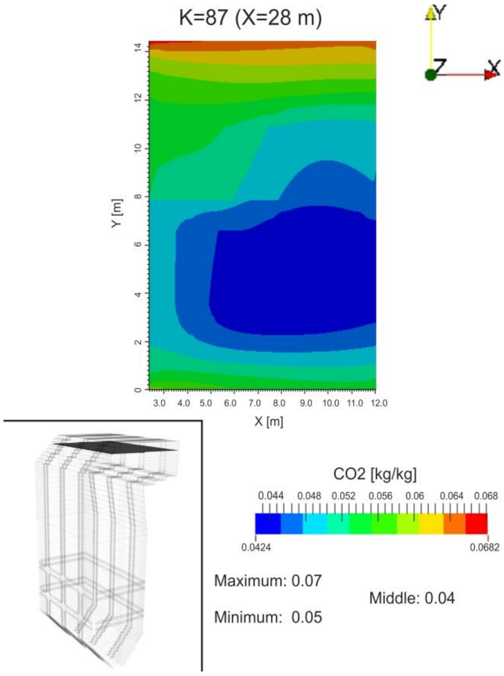


Fig. 18. Distribution of CO_2 concentration at the outlet (z = 28 m) from the furnace combustion boiler BKZ-420.

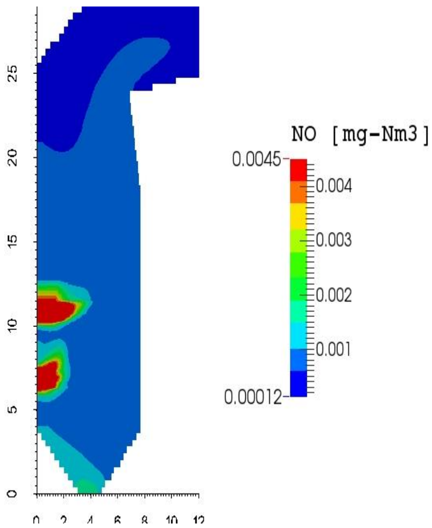


Fig. 19. Distribution of the concentration of NO in the longitudinal section (y = 7.21 m) of the combustion chamber of the boiler BKZ-420.

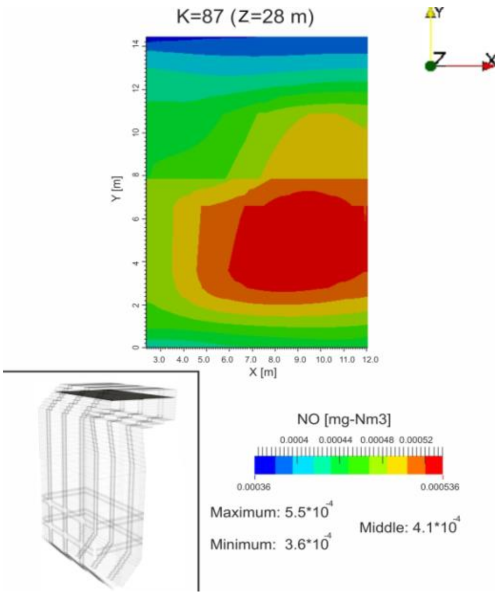


Fig. 20. Distribution of NO concentration at the outlet (z = 28 m) from the furnace combustion boiler BKZ-420.

4. CONCLUSION

(1) In this article the processes of heat and mass transfer during high ash coal combustion in the real combustion chamber of the boiler BKZ-420-7C have been investigated by using second order differential equations of particle motion and methods of control volume.

(2) On the basis of the equations, initial boundary conditions and modeling techniques it was constructed geometric and physical model of the combustion chamber. All stages of the simulation were conducted using the software package FLOREAN. And the results obtained from numerical simulations have been processed in PARAVIEW.

(3) As a result of the numerical simulation of low-grade coal in the combustion chamber of the boiler BKZ-420 we obtained aerodynamic and thermal characteristics of the combustion process. There were obtained the distribution of velocities, temperatures and concentrations of burning products.

(4)Results obtained by means of computer modeling of gas flows behavior, velocity fields due to combustion, radiation and convective heat transfer and the pollutant formation and destruction in furnace of real boilerBKZ-420 can be used to predict main characteristic of combustion process and to provide recommendations for effective boiler performance (Statistical Review of World Energy 2013). Results from numerical simulation can be useful for engineers to choose an appropriate boiler performance for successful furnace and overall combustion process optimization.

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