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COMPUTER MODELING OF CONVECTIVE HEAT AND MASS TRANSFER WHEN BURNING PULVERIZED COAL IN THE COMBUSTION CHAMBER

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The article describes computer modeling of convective heat and mass transfer when burning pulverized coal in the combustion chamber. It also analyzes the works devoted to the numerical modeling of combustion processes. According to official data of the enterprise operating in the Republic annually emit 2.6 million tons and 9.39 million tons of waste.Among heat energy sources major share of emissions falls on the major sources of heat: TPP, HPP. Heat power industry of Kazakhstan is focused on the use of high-ash coals cheap Ekibastuz. As a result of the technology of their production and their use without prior enrichment of the natural environment is experiencing anthropogenic load.Method of research of Ekibastuz coal combustion process in the combustion chamber of Kazakhstan's energy facilities (PC-39 Aksu HPP boiler), proposed in the article allows for similar numerical experiments with any solid fuel to any existing furnace devices units.Computational experiment was carried out on a real energy facility. As of the object selected in the boiler combustion chamber of the PC-39 to the power of 300 MW and steam production capacity of 475t / h. The boiler is installed on Yermakovskaya power plant (Kazakhstan). The combustion chamber is equipped with 12 three-way vortex burners. The burners are arranged oppositely on two levels for 6 burners each.The results allow to make recommendations on the use of new methods of organization of the most favorable of fuel combustion process of pulverized coal torch in order to increase the efficiency of power plants and reduce emissions of harmful substances into the environment.

*Key words**:** Heat and mass transfer, combustion chamber, heat power, boiler.*

1 Introduction

The mathematical model of the process of burning pulverized coal torch can be built based on the following basic system of equations. The initial equations for modeling of turbulent transport in gases and liquids with chemical reactions, as a rule, used the Navier-Stokes equations, supplemented by the corresponding equations of heat transfer and chemical kinetics, conservation equations of mixture components with the influence of the variables properties of the medium, the equations corresponding turbulence model [1].

We write the generalized transport equation migration variable in the tensor form ϕ:

$$\frac{\partial(\rho\phi)}{\partial t} = -\frac{\partial\left(\rho u_j \phi\right)}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\Gamma_\phi \frac{\partial \phi}{\partial x_j}\right] + S_\phi \quad , \qquad (1)$$

where $\frac{\partial\left(\rho u_j \phi\right)}{\partial x_j}$ - change ϕ due to convective transport,

$\frac{\partial}{\partial x_j}\left[\Gamma_\phi \frac{\partial \phi}{\partial x_j}\right]$ - change ϕ due to molecular exchange phenomena,

ϕ - variable transport.

Thus, to solve the problem will be considered by the equation describing the flow, which are derived from the generalized equation:

- The law of conservation of mass (continuity equation),
- The law of conservation of momentum (Navier-Stokes equation),
- The law of conservation of energy (first law of thermodynamics),
- Special case of the law of conservation of the mixture components.

The law of conservation of mass:

$$\frac{\partial \rho}{\partial t} = -\frac{\partial\left(\rho u_j\right)}{\partial x_j} \qquad (2)$$

$\phi = 1 \quad \Gamma_\phi = 0 \qquad S_\phi = 0$

The law of conservation of momentum:

$$\frac{\partial(\rho u_i)}{\partial t} = -\frac{\partial\left(\rho u_i u_j\right)}{\partial x_j} + \frac{\partial \tau_{ij}}{\partial x_j} - \frac{\partial p}{\partial x_i} + \rho g_i \qquad (3)$$

where $\phi = u_i \qquad \Gamma_\phi = \mu \qquad S_\phi = -\frac{\partial p}{\partial x_i} + \rho \cdot g_i + \frac{\partial}{\partial x_j}\left(\mu \cdot \left(\frac{\partial u_j}{\partial x_i} - \frac{2}{3} \cdot \delta_{ij} \frac{\partial u_l}{\partial x_l}\right)\right)$

The Law of energy conservation:

$$\frac{\partial(\rho h)}{\partial t} = -\frac{\partial(\rho u_i h)}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\frac{\mu}{Pr} \cdot \frac{\partial h}{\partial x_i}\right) + S_h \qquad (4)$$

$$\varphi = h \qquad \Gamma_{\phi} = \frac{\mu}{\Pr} \qquad S_{\phi} = S_{h}$$

When considering the heat transfer processes in technical reacting flows in the combustion chamber heat transfer by radiation makes the largest contribution to the total heat transfer. In the flame zone of radiant heat transfer contribution is up to 90% and even more. In this regard, the simulation of heat transfer by radiation to reactive currents in the combustion chamber is one of the most important steps in the calculation processes of heat and mass transfer in real combustors [2-4].

In describing the turbulence model the instantaneous transport variables divided by the average and fluctuation. The balance equations are solved for the values averaged. While the influence of turbulent fluctuations on changing values will be modeled using special equations. In this paper we use the Reynolds averaging time. Fluctuations in viscosity is neglected, since the temperature dependence of molecular viscosity is not significant.

Many theories and combustion models are based on a simplified chemical mechanism, which reduces all the chemical processes in the flame of a single reaction with effective kinetic parameters. For processes modeled in this study used a simplified model of an integrated response that takes into account only the key components of the reaction. Multistage reactions can be modeled using one-step reaction patterns and kinetic data thus determined by the slowest step in the reaction. Model of burning pulverized coal used in this paper takes into account the integral components of the reaction of oxidation of the fuel to the stable end products of the reaction. In this case the intermediate reaction, and the formation and modification of unstable intermediate products are not taken into account [5].

In the considered model of combustion in the following stages:

- Pyrolysis volatile yield and coke formation;
- Volatile combustion and carbon monoxide;
- Burning of the coke residue.

As a model of pyrolysis and combustion of volatile pyrolysis one-step model is chosen because in this case, the pyrolysis reaction stoichiometric coefficients can be derived from the data rapid analysis, and this is very important and preferred. Also, this model works reasonably accurately, and in many cases is a good compromise to reduce computational costs [6].

The main characteristics of the studied physical object

Computer experiment was conducted on a real energy facility. As of the object selected in the boiler combustion chamber of the PC-39 to the power of 300 MW and steam production capacity of 475t / h. The boiler is installed on Yermakovskaya power plant (Kazakhstan). Figure 1 shows the total of the combustion chamber of the boiler circuit and split it into elementary volumes for computational experiments. The combustion chamber is equipped with 12 three-way vortex burners. The burners are arranged oppositely on two levels for 6 burners each. To intensify the fire and the creation of favorable conditions for sustainable combustion burners have two sizes, thus allowing for different coefficients of excess air in them: the lower tier $\alpha_{\Gamma} = 1.4$, upper tier $\alpha_{\Gamma} = 0.9$. Fuel is distributed evenly on the tiers.

To intensify the air is supplied to the ignition chamber so that the oxygen contained therein is gradually entered into the response. To this end, the air supplied to the combustion chamber is divided into a primary feed to the mixture of coal dust and the secondary, fed separately from the primary burner through the same or, at least, in addition to them. Portion of primary air is used for drying the fuel in the pulverizing system. Consequently, the primary air is used for three purposes: as a drying agent for transportation and dust into the furnace as a combustible mixture of the reactants [7-10].

Because of the difficulties flaring solid fuel (due to the complexity of fine grinding, ash wear and slagging of heating surfaces, skid their ashes) was developed by way of burning it in a suspended state, called a vortex. The vortex furnaces under sustainable movement of the rotating air flow, which is suspended dust particles of coal. Swirling air flow character fuel creates good conditions for mixing fuel with air, and hence contributes to more rapid and complete fuel burn.

Method of burning solid fuels in the form of dust in the torch has certain advantages over other methods. Milling fuel leads to the fact that the fuel supply in each small when a large dust particle outer surface. This ensures rapid combustion of dust particles. Specks of dust because of the smallness of the sail and move together with the gas stream. The rates of flow is small. Even for large dust particles can be assumed that the relative speed of movement of air equal to the speed. For these reasons, the Nusselt number for the grains approaching the minimum value, and the heat transfer coefficients and diffusion transfer large due to the small particle size. Warming up the burning of dust particles relative to the gaseous medium is low again because of the good heat transfer [11-15].

In coal-fired furnaces there is a strong wind and thermal heterogeneity near the burners. The design of the burner, placing the burners in the combustion chamber, the nature of gas movement have the most significant effect on the ignition and combustion of the coal dust. The process of inflammation is provided by suction of the hot gases from the flame kernel. This causes the temperature of incoming air-powder. In some effect and flame radiation. Warming up coal dust releases volatile, which, mixing with the gases to form a combustible mixture. Calculations show that the rate of oxidation reaction increases rapidly due to temperature increase, despite a decrease in oxygen concentration. Increasing the reaction rate leads to inflammation. In the burner zone, which is carried out ignition torch substantially uniform. However, away from the burners are equalized dust concentration of the combustion products and oxygen, as well as flame temperature section [16].

Construction of a geometric model for numerical simulation

Numerical experiments on the PC-39 boiler combustion chamber were also at work. In this thesis, these studies continue working. The use of new, modern software for the creation of the computational domain is not allowed to apply the restrictions that were imposed on the computational domain of work. Creating a database for the simulation is carried out in several stages, using PREPROZ software. The generated files contain geometric data of the test process, the initial and boundary conditions for the simulation of heat and mass transfer process in reacting flows. With PREPROZ are the basic files that contain background information, which are then used to package FLOREAN programs. This computer software package allows complex computational experiments on modeling of multiphase reacting flows in the areas of real geometry [17].

When creating a geometric model, each wall of the combustion chamber is described separately in the form of numerical codes. First introduced to the wall of the corner points. The inputs and output are defined primarily as a type of holes and then set the spatial position coordinates of burners on certain walls. burner opening (entrance) is described in the form of concentric circles (for round burners), yield - in a rectangle with the corresponding coordinates in the space. In due to the restrictions imposed when creating a geometric model, circular holes have been replaced with an equal rectangular area, which also affected the accuracy of the calculations. In accordance with the desired geometry creates a grid for numerical simulation (Fig. 1). During the creation of the final version of the computational domain, the grid is edited more than once, in order to create the most optimal variant for further calculations of physical processes in the furnace volume. In this embodiment, for computational experiments designed grille size 27h61h60, which contains 98,820 control volumes. In the computational experiments were carried out for 21 648 control volumes (calculation grid 16h33h41). The ability to reduce the amount of control, especially in the area of the burner arrangement, provides a more accurate result. At the same time thanks to advanced computer model that allows to carry out all the computational experiments in this thesis, the calculation time increases slightly.

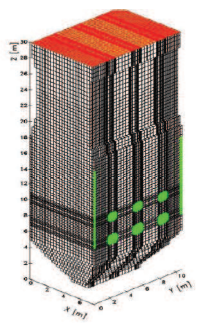


Fig. 1 - General view of the combustion chamber of the boiler PK-39 and split it in control volumes

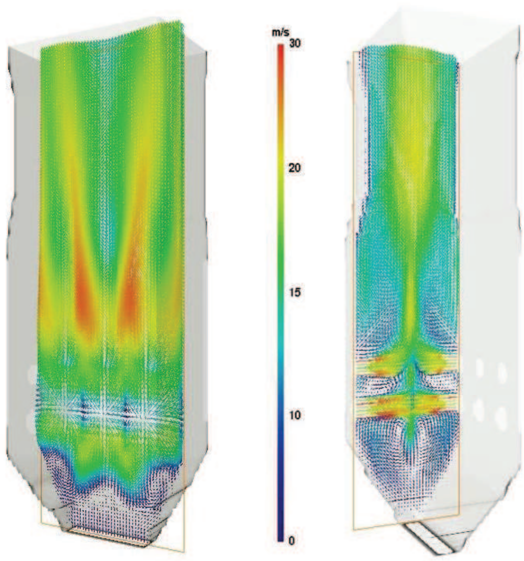
Fig. 2 illustrates the velocity distribution pattern in the combustion chamber, through which the pulverized coal can be described the flow behavior inside the combustion chamber. One can clearly see the fuel supply at different rates through the two burner stages. The central zone is allocated in which the thickening is observed flux lines, thereby improving mixing and increasing the intensity of heat and mass transfer in this area. As seen in Fig. 2, the flame kernel, mixed to the center of the combustion chamber and is determined by the area of the collision flows against burner. Section below the plane of the burners burner flows together with the stream unorganized air drawn from the bottom of the funnel formed counter vortices with velocities directed downward in the plane (XY). In the area of the funnel there is a reverse flow upwards. These air streams entering the vortex of the lower, lower the temperature set fire gases, which can significantly affect the temperature and concentration conditions for ignition and combustion in the main zone. As the distance from the dissemination of the jets from the burner velocity field is leveled and the exit velocity of the gases is reduced [18].

After a jet of gas ejected from the burners environment, causing them to flow increases. At the same initial amount of movement counter flows collide in the center of the firebox (Figure 2) in almost identical speeds in them. Swirling jet supplying fuel through the burner counter located in the plane (XY) when Z = 7,32 m (Fig. 2a) and Z = 10,12 m (Fig. 2b) create a vertical flow volume in the central region of the combustion chamber. In the burners flow moves almost horizontally, and as the upward angle of elevation increases. In the corners of the furnace due to the direct impact on the chamber wall flow spreads, and the angle of elevation increases. Part of the flow is directed slightly angled down evolving into two vortices (Fig. 2). Through intensive whirling motion of dust and gas flows within the combustion chamber greatly increases the residence time of the fuel particles in the furnace, which allows for a more complete burn-out and technically possible to use coal dust larger fractions [19-20].

a) Cross-section Z = 7,32 m b) cross-section Z = 10,12 m

Fig. 2 - Three-dimensional box full speed vector in the burner section

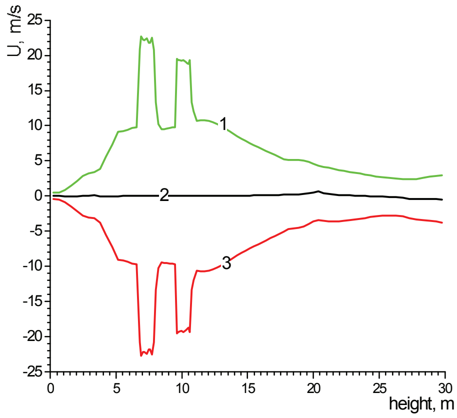
Deep mutual penetration colliding jets and the presence of turbulence-speed cross flow gradients. Considerable turbulence in the flow occurs in the combustion chamber filling good and, therefore, with increased residence time of the combustible mixture in the combustion chamber. Due to the slightly rarefied fill chamber section of the burner in the front and rear walls of the vortices evolve. Part of the upward flow is directed to the exit from the furnace. Excess flow is recycled to form the walls of the burners in the area of the vortex field. Availability flow rotation in the wall area provides even to heating surfaces and reduced



slagging screens, to reduce corrosion and thermal overheating. As the distance from the burner to the plane velocity field is leveled, updraft expands, and the vortex flow pattern is weakening. To exit from the combustion chamber rapidly expands upward flow and the output is uniformly distributed over the entire section.

Thus, the maximum convective transport in consideration of the physical model is observed in the feed mixture and the dust in the symmetry plane of the furnace depth. The nature of the velocity distribution in the volume of the combustion chamber characterizes the established pattern in the chamber: the most intense burning is observed in the central part of the furnace.

Fig. 3-4 shows the calculated values of maximum, minimum and average value of the full rate: U (Fig. 3), V (Fig. 4). Data analysis graphs indicates the symmetry of flow distribution in each section of the combustion chamber. 1 - max 2 - average, 3 - the minimum value



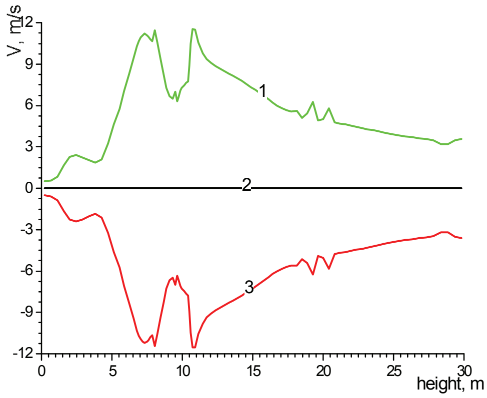


Fig. 3 – Distribution components of velocity U height combustion chamber

Fig. 4 - Distribution V velocity component height of the combustion chamber

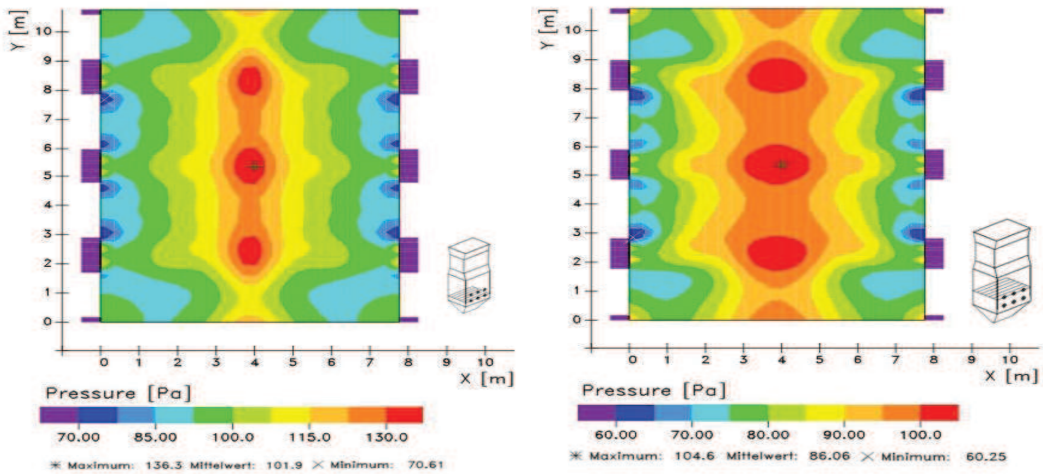


Fig. 5 - The pressure distribution in the furnace in various sections

As can be seen from Fig. 5, the strongest pressure change occurs in the burner arrangement, i.e, in the field of fuel and oxidant. As the distance from the field burner pressure decreases monotonically and the output value is the estimated average value of p ~ 25.4 Pa.

The numerical study of aerodynamic characteristics of the combustion process in the combustion chamber testify to the complexity of the ongoing process. These results suggest that the location of the burners zone there vortex flow due to the location of burners and vortex method of supplying coal dust flows into the combustion space. The presence of vortex motion provides faster ignition and flame stabilization. Hot gases entrained in the torch heated combustible mixture and intensify inflammation. Active updrafts also engaged in the region near the walls of the furnace, which in turn has an impact on the convective component of heat transfer in the combustion chamber. Swirl nature of traffic flow inside the combustion chamber leads to increased flare ignition at the exit of the burner, and enhanced heat and mass transfer in a vortex intensifies burning. Thus it is possible to achieve uniform heating of the surfaces of the combustion chamber and reduce their slagging that renews the equipment. Due to the circulation of particles in a vortex flare combustion takes place with sufficient detail, even with coarsely ground, which can significantly extend the range of use of coal dust.

In this way, the organization spread of dust and gas flow in the combustion chamber creates favorable conditions for the intensification of the combustion process. Sustainable lighting is provided by forced hot combustion gases in flares interrivulet space counter flows, as well as the presence of a moderate vortex formed in the cold and the funnel over the torch.

Conclusion

The research results were taken investigated using dynamic characteristics of pulverized coal for:

• Based on the three-dimensional problem solutions describing the process of convective heat and mass transfer in the combustion chamber to study the effect of plasma activation of pulverized coal on the aerodynamic and thermal characteristics of the process (pressure field, full rate, turbulent characteristics, temperature).

• Activation of pulverized coal flow has a significant effect on the flow field: on the distribution volume of the reacting stream in the furnace, mixing processes in the jet, the size, shape currents. Increasing the speed of the torch along the axis of high mixing intensity increases the flue gases, which in turn leads to faster growth temperature of the particles, and hence to improve the ignition of pulverized coal flame burner is not equipped with TCP.

The results allow to make recommendations on the use of new methods of organization of the most favorable of fuel combustion process of pulverized coal torch in order to increase the efficiency of power plants and reduce emissions of harmful substances into the environment. The proposed calculation method can be used on any energy facilities of the Republic of Kazakhstan, using as a primary energy source low-grade coals.

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