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Numerical simulation of high-ash Kazakh KR-200 coal combustion in the combustion chamber of SB-39

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Abstract

Using the low-grade solid fuels in power engineering makes difficulties in solving environmental problems associated with hazardous emissions into the environment, as well as the efficient use of energy facility. Using a package of applied programs FLOREAN was investigated combustion process Kazakh coal brand KR-200 with high ash content. Numerical experiments were obtained temperature distribution of combustion, emission concentrations of carbon monoxide, carbon dioxide and nitrogen containing harmful components throughout the volume of the chamber and at the exit. Also were determined the convective and radiative heat flux value in the combustion chamber and the distribution of the total heat flux to the walls of the combustion chamber. Investigated heat processes on the boundary surfaces of the combustion chamber, which allows predetermining and eliminating the risk of overheating of the heating surfaces and providing the necessary heat flux distribution to the walls of the combustion chamber. Given results of numerical simulation of the combustion process make possibilities to make suggestions for organizing efficient and cleaner burning of low grade solid fuels with high ash content.

Keywords: Coal combustion, numerical simulation, high-ash content, emission into the atmosphere.

Introduction

Kazakhstan explored more than 100 deposits of coal with total geological reserves of about 176.7 billion tons. However, the most studied about 40 fields, with industrial resource estimate of approximately 34.1 billion tons. Main largest deposits are located in Northern and Central Kazakhstan: Karaganda (9.3 billion tons), Turgay (5.8 billion tons) and Ekibastuz (12.5 billion tons). It is shown that open-pit mining is possible to extract more than 400 million tons of coal a year. Industrial reserves of coal suitable for open-pit mining amount to about 21 billion tons and are concentrated mainly in Ekibastuz (51%), Thurgau (26.4%), Maykubene (8.8%) and Shubarkol (7%) coal basins [1].

Thermal power plants are using solid fuel where the coal is dominant. With use of low-grade coal in the domestic industry is extremely important development and introduction of new energy-saving technologies use solid fuel and reducing emissions of pollutants [2-6]. Approximately 50% of the emission of pollutants produced by thermal enterprises, and about 33% - the metal and mining industries.

Mathematical model

The bases of a mathematical model of the flow of gases or liquids are the equations of conservation of mass and momentum. For flows in which the process of heat transfer, and for compressible media must also solve an equation of conservation of energy. During the mixing process with the various components, with combustion reactions, and etc. it must be added the equation of conservation of components of the mixture or the conservation equations for a mixture of fractions and their changes. For a description of turbulent flows is complemented by a system of equations of transport equations for turbulent characteristics.

To place a mathematical problem, consider the fundamental equations [7].

The law of conservation of mass. The equation of conservation of mass, or the continuity equation can be written as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = S_m \quad \textbf{(1)}$$

In our study, there are no sources of weight; there is only the transformation of the components. Therefore, the law of conservation of mass can be written as:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad \textbf{(2)}$$

The law of conservation of momentum. Keeping the momentum in the *i*-direction in the inertial frame is as follows:

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

where p - static pressure is represented in the form of the stress tensor, ρg_i and F_i - force of gravity and external mass forces (e.g., forces resulting from the interaction of the dispersed phase) in the *i*-direction, respectively.

The stress tensor is determined by the ratio:

$$\tau_{ij} = \left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] - \frac{2}{3}\mu\frac{\partial u_l}{\partial x_l}\delta_{ij} \qquad \textbf{(4)}$$

The energy equation:

The change of energy in reacting turbulent flows can be caused by the following processes:

-the total energy flow by convection;

-the total energy flow due to molecular heat transfer;

-change of energy due to operation of the pressure forces on the surface of the control region; the change in energy due to the work of the friction forces on the surface of the control volume;

-the change in energy due to the work of body forces;

-absorption (separation) energy as a result of chemical changes, or due to the energy of the thermal radiation.

With the above changes the energy equation in the general form is written:

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}(u_i(\rho E + p)) = \frac{\partial}{\partial x_i}\left(k_{eff}\frac{\partial T}{\partial x_i} - \sum_{j'} h_{j'} J_{j'} + u_j(\tau_{ij})_{eff}\right) + S_h$$

The equation for the components in general terms, the equation for the concentration of mixture components can be written as:

$$\frac{\partial}{\partial t}(\rho c_n) + \frac{\partial}{\partial x_i}(\rho u_i c_n) = \frac{\partial}{\partial x_i}\left[\frac{\mu_{eff}}{\sigma_{c_n,eff}}\frac{\partial c_n}{\partial x_i}\right] + S_{c_n}$$

Modeling of turbulence. Technical trends are mostly turbulent. Turbulent flows are characterized by velocity fluctuations. These pulsations transported promote mixing characteristics such as momentum, energy, and concentration of the components, and cause fluctuations in these characteristics. In this paper a simple two-parameter model of turbulence is used. It solved two transport equations that define the turbulent velocity and length scale. The standard *k-ε* model has been widely used in solving many technical problems. It was first proposed by Launder and Spalding [8-9].

The standard *k-ε* model is written two major transport equation turbulent characteristics *k* and *ε*:

$$\rho\frac{dk}{dt} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right) + G_k + G_b - \rho\varepsilon - Y_M$$

$$\rho\frac{d\varepsilon}{dt} = \frac{\partial}{\partial x_i}\left(\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \varepsilon}{\partial x_i}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

The empirical constants *k-ε* turbulence model proposed in this work [*10-12*]: $C\mu = 0.09$; $\sigma_k = 1.00$; $\sigma_\varepsilon = 1.30$; $C_{1\varepsilon} = 1.44$; $C_{2\varepsilon} = 1.92$.

As an object of study in this paper were selected the combustion chamber of the boiler SB-39 to the power of 300 MW and steam production capacity of 475t/h. The boiler is installed on the Aksu power plant (Kazakhstan). The combustion chamber is equipped with 12 three-way swirl burners. The burners are arranged oppositely in two tiers to 6 burners each. Characteristics of the KR-200 coal and geometry of the combustion chamber of the boiler SB-39 are given above in Table 1.

Figure 1 presented the general view of the division into the cells of combustion chamber of the boiler SB-39 on Aksu TPP.

The vortex furnaces under sustainable movement of the rotating air flow, which is suspended pieces of coal (d~15-90 microns). Swirling motion fuel nature airflow creates good conditions for mixing fuel with air, and hence contributes to more rapid and complete combustion of the fuel.

Table 1 Characteristics of the combustion chamber of the boiler SB-39 Aksu TPP

Name characteristics and it's dimension	Value
The composition of the KR-200 coal (%)	
W	***7.0***
A	***40.9***
S	***0.8***
C	***41.1***
H	***2.8***
O	***6.6***
N	***0.8***
The diameter of the coal particles, micron	***30.0***
The height of the furnace, m	**29.985**
Width of furnace, m	**10.76**
Depth of furnace, m	**7.762**

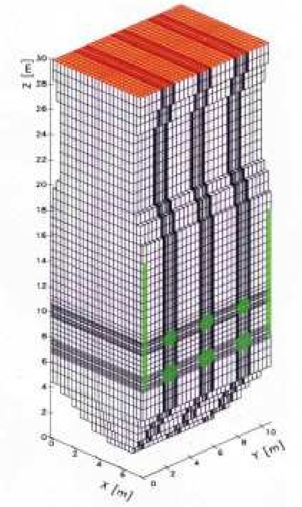

Figure 1 General view of the division into the cells of combustion chamber of the boiler SB-39 on Aksu TPP.

The results of computational experiments

Figure 2 shows the distribution of average values of the adjustment of heat flux due to radiation in the coordinate directions *x*, *y* and *z*. Analyzing the distribution of the values of heat flow by radiation it can be concluded that in the *z*-direction flow of heat takes a largest value in the entire volume of the combustion chamber as compared with the values in the *x* and *y* directions.

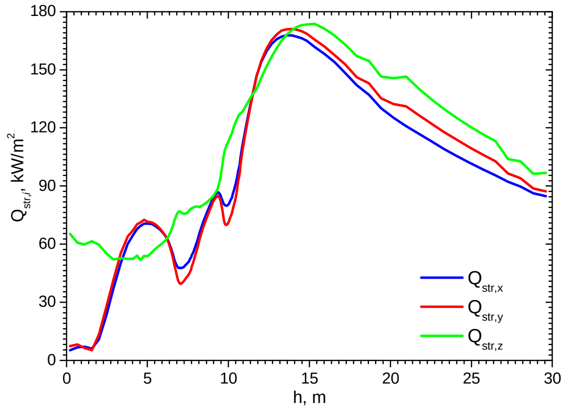

Figure 2 Distribution of average height values of heat flux due to radiation in the coordinate directions *x*, *y*, *z*.

The primary zone of the combustion chamber - the gases involved in the process of heat transfer, have a high temperature and undergo rapid physical and chemical changes. Furthermore, additional problems arise due to the existence within the primary zone of sharp temperature gradients, velocity and composition of the fuel-air mixture.

In most cases it is very convenient to determine the convective heat transfer under the assumption that the heat flux from the flame to the heating surface is equal to the product of the convection heat transfer coefficient h_c and the difference between the gas temperature T_g and surface T_w. Thus we can write:

$$q_C = h_C (T_g - T_w)$$

However, in solving many nonlinear problems h_c it is directly a function of the temperature difference, and other parameters. In this case, the problem is greatly complicated. For example, the convection heat transfer coefficient for a cylindrical combustion zone defined by the ratio [13]:

$$Nu = \frac{h_C d}{\lambda_C} = 0.0207\,\mathrm{Re}^{0.8}$$

Convective heat transfer in the combustion chamber, the process is well established. Most of chambers are water-tube type, convective heat transfer in collisions - the main cause of overheating or failure of the pipe in the combustion chambers. Therefore, despite the relatively small value of the convective transport in comparison with radiation, it needed to get as much information on convective heat transfer.

Figures 3-4 shows the results of 3D numerical modeling of convective heat transfer on the surfaces of the combustion chamber of boiler SB-39. The heat flux due to convection represented as three-dimensional distributions for each of the boundary surface of the combustion chamber.

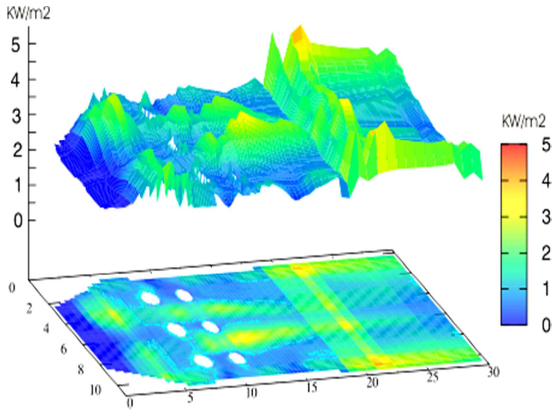

Figure 3 Three-dimensional distribution of the convective heat flux on the front wall of the combustion chamber of the boiler SB-39.

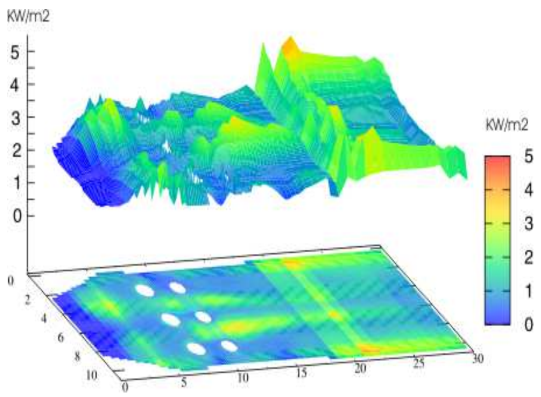

Figure 4 Three-dimensional distribution of the convective heat flux on the back wall of the combustion chamber of the boiler SB-39.

Three-dimensional distribution of the total heat flux on the wall of the chamber is shown in Figure 5. It is seen that the maximum heat transfer is observed in the region of the burners. This is due to the fact that the maximum heat generation occurs in the central part of the combustion chamber, in the region where the most efficient chemical transformations occur with intense heat through chemical reactions and radiation.

As already noted, the main part of the heat is converted to the combustion process, is heat by radiation. Comparative analysis of the figures 3-5 confirms that if we compare the distribution of heat on the front wall of the combustion chamber in this case, the maximum convective heat flow to the wall is not more than 5 kW/m^2), while for radiation heat flux of 300 kW/m^2.

The maximum thermal load is observed on the side walls, in which there are no burners. The maximum heat flow values correspond to the central part of the combustion chamber, namely, the area with the highest physical and chemical transformations and interactions.

Figure 5 shows comparative heat flux distribution along the perimeter of the combustion chamber. It also marked the contours for the respective values of the total heat flow.

Thus, we have developed a numerical model for the study of convective and radiative heat transfer in the combustion chamber, which allows to determine the values of the heat flows in the solid surfaces of the combustion chamber. The results of computational experiments obtained by the basic laws of heat flux distribution in the volume of the combustion chamber and the values of the radiation, convective and total heat flux on its walls.

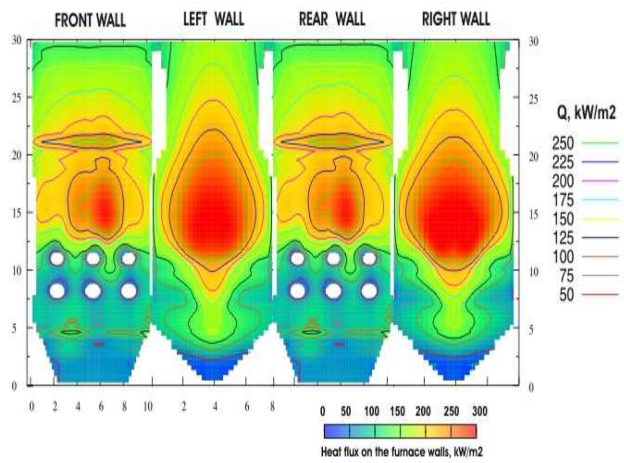

Figure 5 Distribution of the total heat flux on the walls of the combustion chamber of the boiler PK-39.

Conclusion

The computer experiments were made to study the process of heat transfer in the combustion chamber of the boiler SB-39 on Aksu TPP. The results of computational experiments obtained by the basic laws of heat flux distribution in the volume of the combustion chamber and the values of the radiation, convective and total heat flux to the walls of the combustion chamber. It is shown that the highest heat load is a central region of the combustion chamber wall and an arrangement region of the burners, where the total heat flow reaches a maximum of about 300 kW/m^2. The maximum convective heat flow to the wall is not more than 5 kW/m^2, while for the flow of heat by radiation the value is 300 kW/m^2. The maximum heat load occurs at the side walls on which no burners. The maximum heat flow values correspond to the central part of the combustion chamber, namely the area of intensive physical and chemical transformations and interactions between the fuel (coal) and an oxidant (air).

References

[1] Statisticheskiy sbornik «Toplivno-energeticheskiy balans» - Almaty: Agentstvo RK po statistike, 2003, 124 s.

[2] Askarova, A., Bolegenova, S., Safarik, P., Maximov, V., Beketayeva, M., (2015), 3D Modeling Of Coal Combustion At Power Stations Of The Republic Of Kazakhstan, Journal of Thermal Science, Vol.24 (3), pp. 275-282.

[3] Askarova, A.S., Bekmukhamet, A., Bolegenova, S.A., Beketayeva, M.T., Maximov, V.Yu., Ospanova, Sh.S., Gabitova, Z.K., (2014), Numerical modeling of turbulence characteristics of burning process of the solid fuel in BKZ-420-140-7c combustion chamber, International Journal of Mechanics, Vol.8, pp. 112-122.

[4] Askarova, A.S., Bolegenova, S.A., Bolegenova, S.A., Maximov, V.Yu., Bekmukhamet, A., Beketayeva, M.T., (2013), Numerical experimenting of combustion in the real boiler of CHP, International Journal of Mechanics, Vol.7 (6), pp. 343-352.

[5] Askarova, A., Bolegenova, S., Bekmukhamet, A., Maximov, V., Beketayeva, M., Ospanova, Sh., Gabitova, Z.K., (2014), Investigation of turbulence characteristics of burning process of the solid fuel in BKZ 420 combustion chamber, WSEAS Transactions on Heat and Mass Transfer, Vol.9, pp. 39-50.

[6] Askarova, A.S., Messerle, V.Ye., Ustimenko, A.B., Bolegenova, S.A., Maksimov, V.YU., Gabitova, Z.KH., (2015), Chislennoye modelirovaniye goreniya pyleugol'nogo topliva v kamere sgoraniya energeticheskogo kotla, TVT, Tom.53 (3), 467–474.

[7] Müller, H., (1997), Numerische simulation von Feuerungen. CFD–Vorlesung, TU. – Braunschweig: IWBT. – 8–12 s.

[8] Launder, B., Spalding, D., (1974), The numerical computation of turbulent flows, Comp. Meth-s. Appl. Mech. Eng.

[9] Patankar, S.V., (1980), Numerical Heat Transfer and Fluid Flow, Taylor & Francis.

[10] Ehlers, C., Leithner, R., (2000), Clean Coal Utilization with highest Efficiency, 12th International Conference on Coal Research Proceedings, Sandton, South Africa, 2000. P.1-919783-17-2.

[11] Askarova, A.S., Messerle, V.E., Ustimenko, A.B., Bolegenova, S.A., Maksimov, V.Y., (2014), Numerical simulation of the coal combustion process initiated by a plasma source, Thermophysics and Aeromechanics, Vol.21 (6), pp. 747-754.

[12] Askarova, A.S., Karpenko, E.I., Messerle, V.E., Ustimenko, A.B. Modeling of Coal Combustion Activated by Plasma Flame, Presentations Abstracts of 30th International Symposium on Combustion, Chicago, 2004, P. 423.

[13] Sobolev, V.V. Kurs teoreticheskoy astrofiziki. - M.: Fizmatgiz, 1985. – 235 s.