Investigation of turbulence characteristics of burning process of the solid fuel in BKZ 420 combustion chamber

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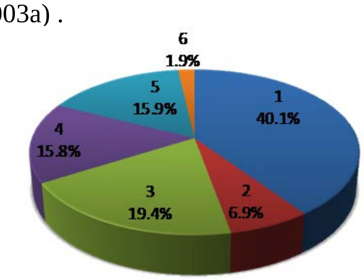
***Abstract*—** In this paper the results obtained by the numerical method modeling of Ekibastuz coal burning in BKZ-420 combustion chamber of Kazakhstan Power Plant. There are devoted to the numerical simulation of the furnace boiler BKZ-420, its steam generating capacity equal 420 T/h. Boiler (Fig. 2) has six vortical pulverized coal burners arranged in two levels with three burners on the front wall of the boiler. Burned in the furnace high ash,low-grade coal from Ekibastuz, Its ash content 40%, volatile 24%, humidity 5%, highest calorific value 16750 kJ/kg. Milling dispersity of coal was equal to R90 = 15%.

***Keywords*—** Combustion, Heat and mass transfer, BKZ-420, turbulence, pulverized coal, two–phase flows, Ekibastuz coal.

I. Introduction

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 utilisation history, it is still one of the most important fuels for the generation of primary energy, especially of electric energy (Fig.1). According to 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 utilisation of coal is expected in the future (IEA, 2003a) .



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)

Figure 1. Total world electricity generation by fuel

Solution of many technical tasks impossible without using of CFD software packages, allows modeling of difficult particular process in practice. In this article investigated numerical study of physical characteristics and aerodynamic properties of pulverized flue combustion in thermal power plant with Florean [1-3] program complex.

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

There are devoted to the numerical simulation of BKZ-420 combustion chamber. Its steam capacity equal 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. In the boiler has burnt dust low-grade high-ash coal from Ekibastuz, with ash content 40 %, volatile 24 %, moisture content 5 % and the highest calorific value 16700 kJ / kg. The fineness of coal milling is equal to R90 = 15 %. All numerical calculations were performed on above methodology.

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).

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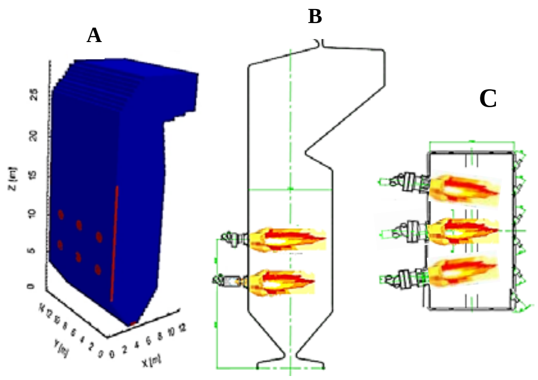


A -3D view of BKZ 420 boiler and its breakdown into control volumes
B- Burners establish arranged on two levels
C – Top view on the cross section (h = 10.75m)

Figure 2 - General view of the industrial boiler BKZ-420 of the Almaty TPP-2

Industrial implementation of any new technology is not possible without preliminary analysis of advantages and disadvantages 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.

Products of combustion contain different harmful substances and the emission of this components grows in to 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), sulphur dioxide, acid sulphate, lead combinations and different hydrocarbons etc (Table-1).

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.

In this paper software package FLOREAN [2] for 3-D 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 [3].

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 transfer six stream model. The mathematical description of the physical and chemical processes are based on the solution of the equation balance. 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.

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

Characteristic	Quantity
Coal type	Ekibastuz
Density of particles	1300 kg/m^3
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	72 000.00 kg/h
Consumption of coal to the burner through two channels	12 000.00 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 ^{o}C
Temperature of aeromixture	88.85 ^{o}C
The average particle size of coal	64 мкм
The lower heating value of coal	16 750 kJ / kg
The amount of computation (control volumes)	671113

II. MATHEMATICAL MODEL

Program FLOREAN is based on the numerical solution of the Reynolds averaged balance equations for mass, species, energy and momentum [1,2, 3, 4]. 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 closed by the k-ε turbulence model.

The changes of the concentrations of the 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 model by Lockwood etc [5].

Pulverised 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 written basic transport equation of turbulent kinetic energy k:

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

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

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

The equation for the turbulent kinetic energy dissipation ε:

$$\frac{\partial(\bar{\rho}\varepsilon)}{\partial t} = -\frac{\partial\left(\bar{\rho}\,\bar{u}_j\varepsilon\right)}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\frac{\mu_{eff}}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{\varepsilon,1}\cdot\frac{\varepsilon}{k}\cdot P - C_{\varepsilon,2}\cdot\frac{\varepsilon^2}{k}\cdot\bar{\rho} \qquad (3)$$

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

$$\mu_t = C_\mu\cdot\rho\cdot\frac{k^2}{\varepsilon}$$ where - empirical constant.

$C_\mu = 0.09$; $\sigma_k = 1.00$; $\sigma_\varepsilon = 1.30$; $C_{1\varepsilon} = 1.44$; $C_{2\varepsilon} = 1.92$.

The boundary conditions for the turbulence model are defined as follows:

$k_{in} = 1.5(u_{i,in}Tu)^2$ - kinetic energy of turbulence at the inlet.

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.

III. RESULTS OF CFD RESEARCH

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. In Figure 3-7 are the vector field full speed $V = \sqrt{u^2 + v^2 + w^2}$ throughout the volume of the combustion chamberby 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[5].

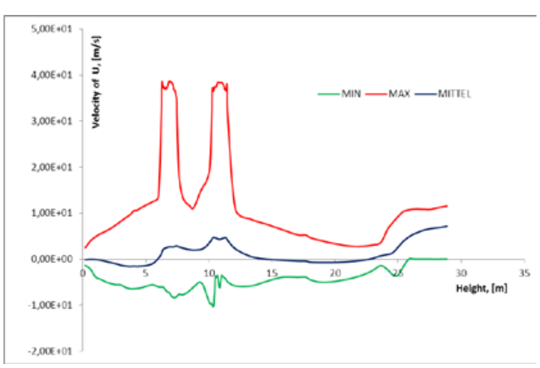


Figure 3- Distribution of the vector velocity direction of the ***x*** axis height of the combustion chamber of the boiler BKZ-420

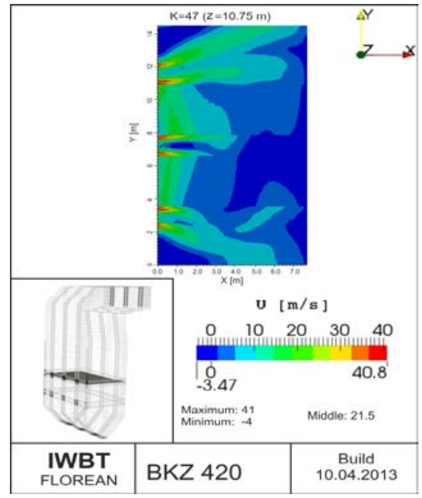


Figure 4- Velocity profile on the cross section of the combustion chamber of the boiler BKZ-420 (K=47, Z = 10.75m)

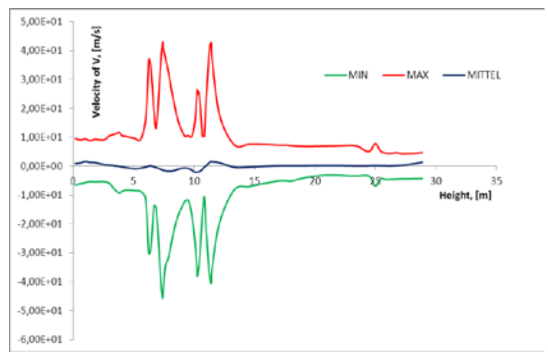


Figure 5- Distribution of the vector velocity direction of the ***y*** axis height of the combustion chamber of the boiler BKZ-420

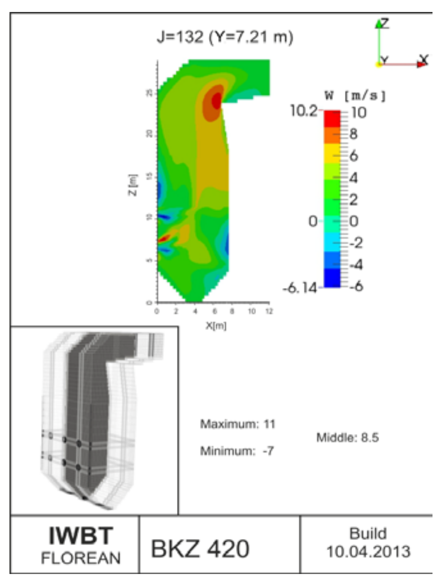


Figure 6- Velocity profile on the cross section of the combustion chamber of the boiler BKZ-420 (J=132, Y = 10.75m)

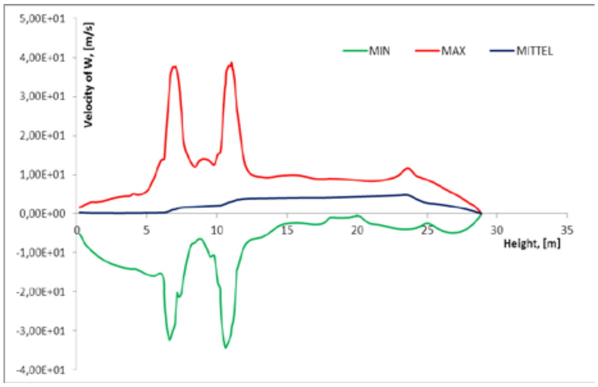


Figure 7- Distribution of the vector velocity direction of the ***Z*** axis height of the combustion chamber of the boiler BKZ-420.

Figure 4 - in the cross section, which accounts for the lower tier of burners (K=47, h = 10.75m) has max speed on the inlet, it equal 40 m/s, Figure 5- distribution of the vector velocity direction of the ***y*** axis height of the combustion chamber of the boiler BKZ-420, there are we can see two pics , its mean is speed on the inlet of burner.

Figure 6-7 Velocity profile on the cross section of the combustion chamber of the boiler BKZ-420 (J=132, Y = 7.2 m) by Z aixs. There are max speed equal to W=11 m/s.

Speed vector Fields in the figures are 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 Figures-8 able to obtain whole velocity profile in the BKZ-420 chamber include three different level by Y axis: Y_1 = 2.85 m, Y_2 = 7.2 m, Y_3 = 11.69 m.

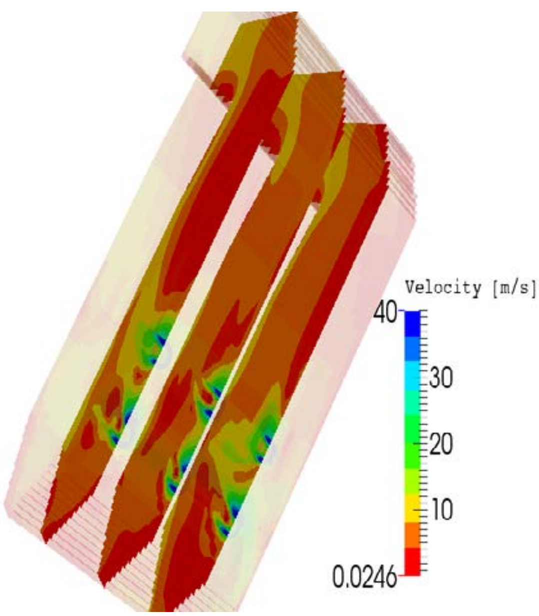
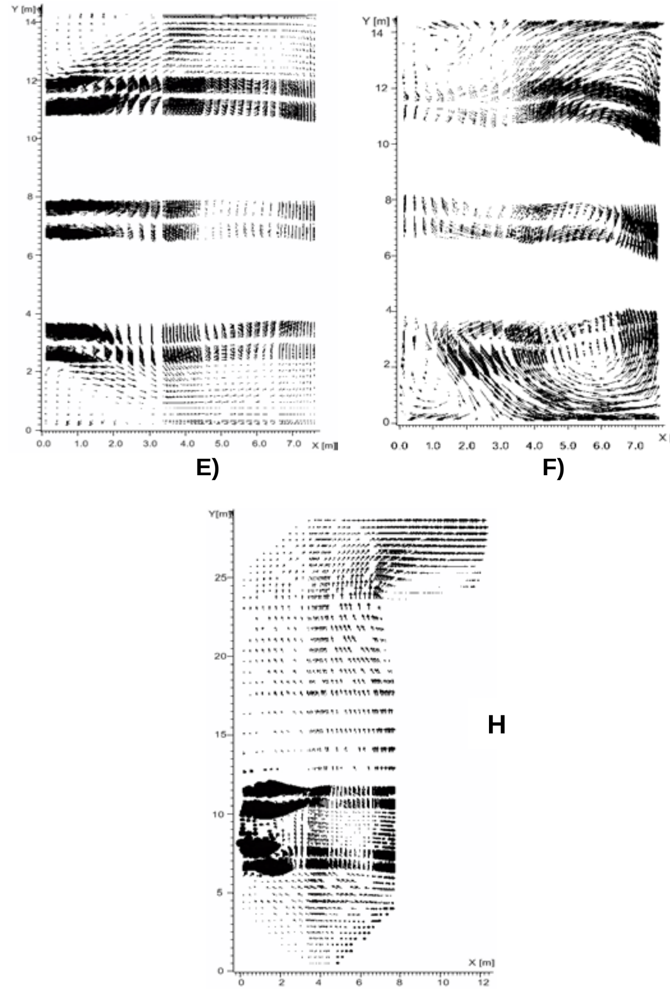


Figure 8- Velocity profile on the different levels of the combustion chamber Y_1 = 2.85 m, Y2 = 7.2 m, Y_3 = 11.69 m on the Y axis for two longlines (z1 = 6.2 m) and (z2 = 10.75 m).



E-(Z_1=10.75 m), F-(Z_2=6.2 m), H-(Y=7.2 m)

Figure 9 – Velocity vector profile by the combustion chamber height

The Figure 9 illustrates the picture of 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 above all of the figure we can see max velocity on the inlet of burner, also on the cross section by Z axis F-(Z_2=6.2 m), Right and left side of burner exist turbulence flow of combustion.

On the basis of mathematical models and 3D computer modeling had conducted the study of complex of heat exchange processes taking place during combustion of low-grade coal fuel (Ekibastuz caol) 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 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.10 that max pressure on the below opposite side burner.

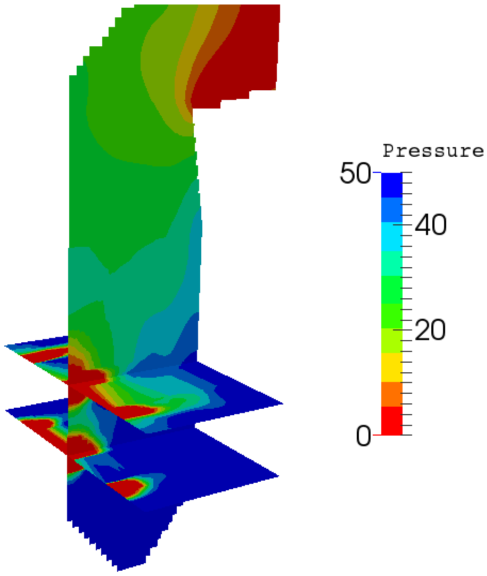


Figure 10 – Pressure profile by the height of combustion chamber

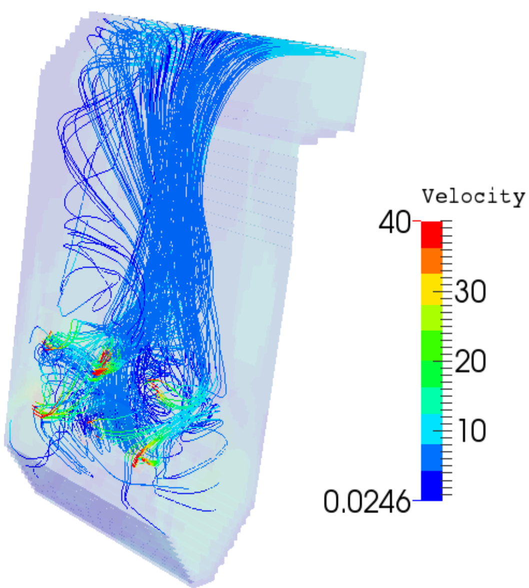


Figure 11 –3D view of turbulence combustion profile by the by the height of combustion chamber

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 boiler BKZ-420 can be used to predict main characteristic of combustion process and to provide recommendations for effective boiler performance. Results from CFD simulation can be useful for engineers to choose an appropriate boiler performance for successful furnace and overall combustion process optimization[6].

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