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3D MODELING OF HEAT AND MASS TRANSFER IN INDUSTRIAL BOILERS OF KAZAKHSTAN POWER PLANT

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At the present work by means of 3D–Finite Volume simulation tool FLOREAN developed at the Institute for Heat and Fuel technology TU Braunschweig heat and mass transfer processes in furnaces with swirl burners in box-firing system are considered. The obtained results describe combustion processes in the way of 3D fields of temperatures, velocities and concentrations of the combustion products CO, CO2 etc.

Key-Words: *Computational fluid dynamics, Combustion, Heat and mass transfer, Boiler performance, Pollutant Emissions.*

Introduction. At the present time the main subject of engineers devoted mainly towards the utilization of the energy sources in more efficient and economical way. 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. Heat transfer problems pertaining to the combustion in industrial furnaces are of great importance to the engineering designer of boilers and steam generators. In most industrial flame applications, the achievement of high heat transfer rates is a main target and is desirable.

At the present work by means of 3D–Finite Volume simulation tool FLOREAN developed at the Institute for Heat and Fuel technology TU Braunschweig heat and mass transfer processes in furnaces with swirl burners in box-firing system are considered.

Mathematical model. Program FLOREAN is based on the numerical solution of the Reynolds averaged balance equations for mass, species, energy and momentum [1–4]. 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 submodels. 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.

Coal combustion model is evaluated in several steps: devolatilization, ignition and combustion of volatiles and char burn out. The combustion of volatiles in the gas phase is supposed to be controlled by turbulent mixing, using the eddy dissipation concept. The char reaction rate is governed by the rate of oxygen diffusion to the surface and the kinetic rate of chemical reaction at the surface. The effect of char combustion on the mean particle diameter and particle density is taken into account after suggestion of Field [6].

Results of CFD Studies

Kazakhstan has huge stocks of power resources, sufficient for covering own needs and export to other regions, both in a natural, and in the form of electric power. About 3,3 % of world industrial stocks of coals are concentrated in Kazakhstan. More than 70 % of the electric power in Kazakhstan are generated in Thermal Power Plants. Thermal power plants predominantly use bituminous and sub-bituminous coals from Ekibastuz, Karaganda, Kuuchekinsk. Coals from these basins have almost the same characteristics. All Kazakhstan coals are considered to be low-rank. The moisture content varies from 5 to 40% and the high ash content is up to 55 %. The volatile matter content reaches up to 28 %. High ash content results in high fly ash contents in flue gases, which reach up to 60-70 g/m3 for high ash coals.

Calculations presented for furnace chamber of a 390 MW power station fired with low grade coal of Ekibastuz (Kazakhstan). The general view of the combustion chamber is represented at Fig. 1. The burner of the boiler is installed by 12-whirl nozzles. The nozzles are located opposite to each other in two layers, 6 nozzles in each. The fuel in layers is distributed equally. In order to intensify the ignition process the air is fed to the chamber in such a way that oxygen, it contains, comes into reaction gradually. Scheme of flows in cross section of the furnace in the level of the burners and vertical section are shown at Fig. 2.

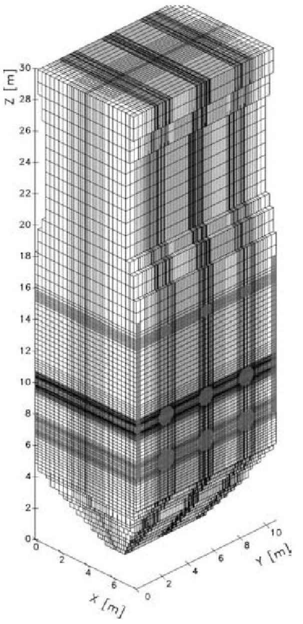


Fig. 1. Scheme of the furnace PK39

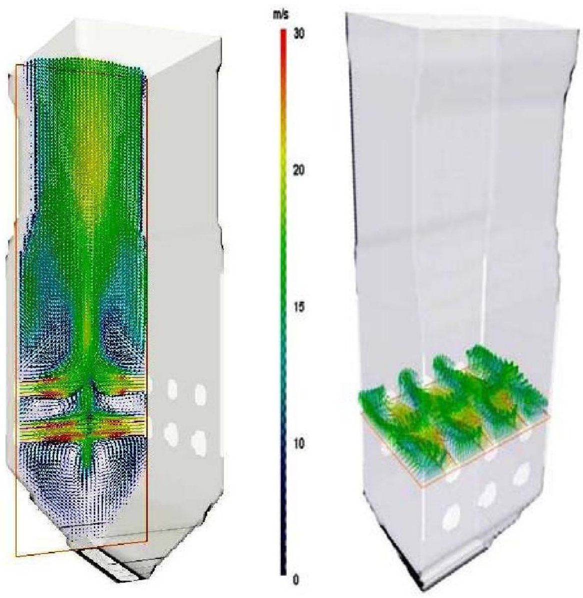
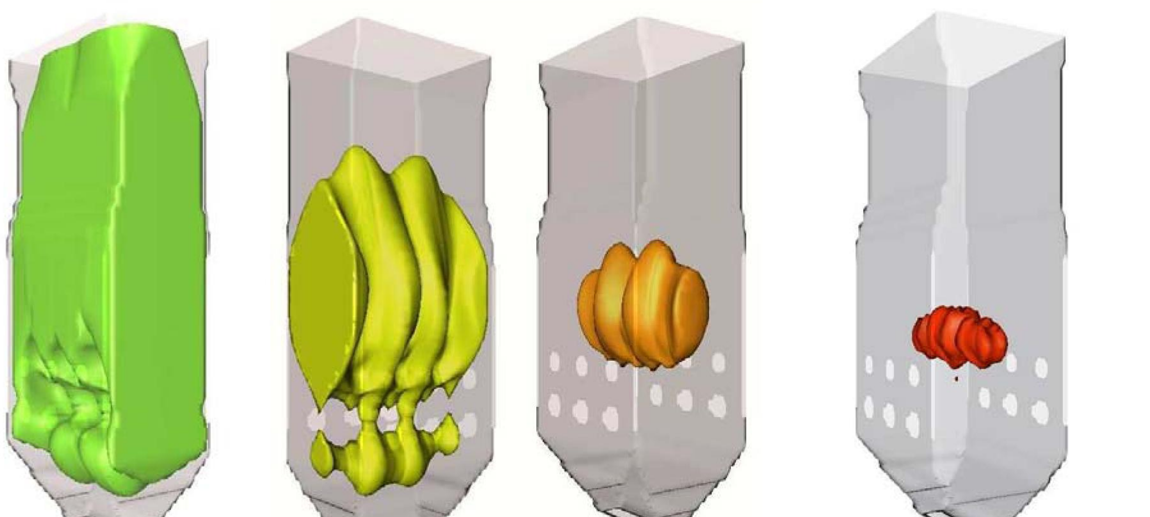


Fig. 2. Scheme of flows

Temperature distribution in furnace volume for full load boiler operation are presented in the shape of temperature isosurfaces (Fig. 3). It's seen that zone of maximum temperatures are concentrated in the center of the fire-chamber on the level of the burners.



T = 1200 grad C   T = 1400 grad C   T = 1600 grad C   T = 1750 grad C

Fig. 3. Temperature isosurfaces

The existing of minima in presented temperature field caused by low temperature of fuel and transporting gas supplied to furnace through the burners nozzles.

Fig. 4 and 5 show the temperature distribution in cross section of the furnace in the lower level of the burners and in vertical section due to symmetry plane of combustion chamber. It's seen that maximum temperatures is in the center of the fire- chamber on the level of the burners. Here the intensive combustion took place.

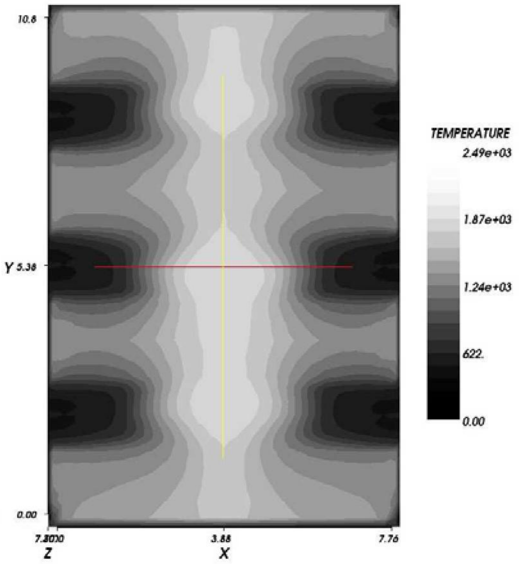


Fig. 4. Temperature distribution in cross section of the furnace in the lower level of the burners

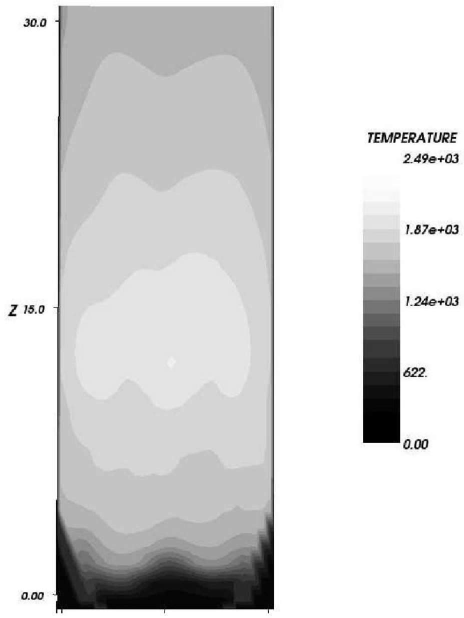
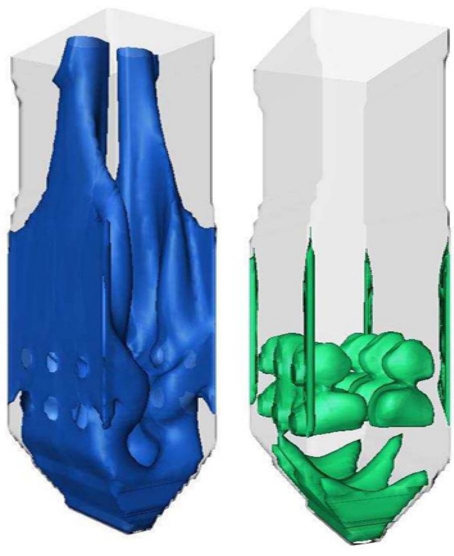


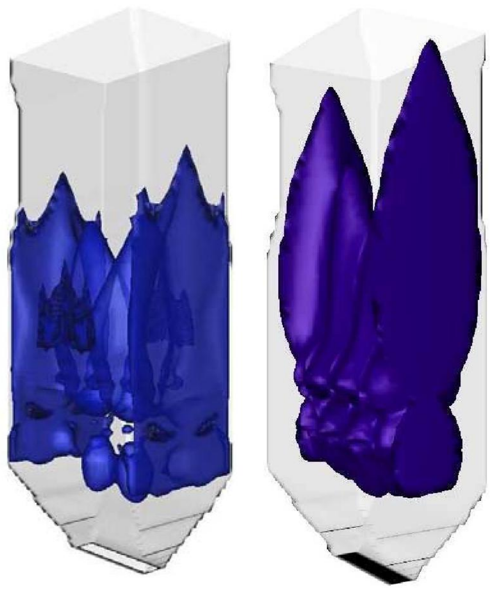
Fig. 5. Temperature distribution in cross section of the furnace in the lower level of the burners

Fig. 6-8 shows results of combustion products calculations for low grade Kazakhstan hard coal power station. Concentration isosurfaces show concentration of O_2, CO and CO_2 distribution inside of the furnace space.



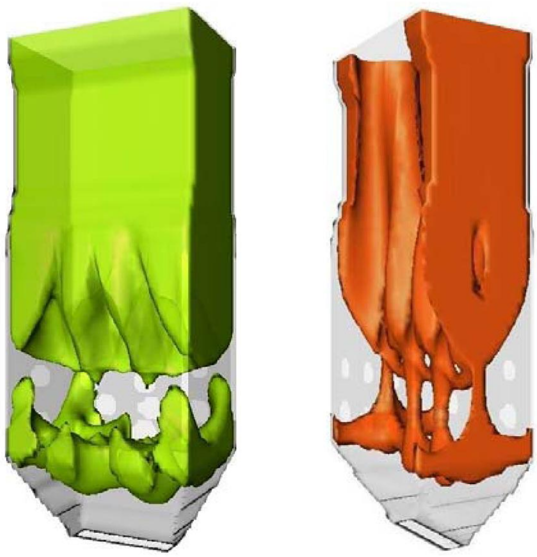
cO2 = 0.05 kg/kg cO2 = 0.10 kg/kg

Fig. 6. Oxygen isosurfaces



cCO = 5 . 103 mg/Nm3 cCO = 2 . 103 mg/Nm3

Fig. 7. Carbon monoxide isosurfaces



cCO2 = 0.12 kg/kg cCO2 = 0.16 kg/kg

Fig. 8. Carbon dioxide isosurfaces

The picture of fuel burning out is shown in Fig. 6-8 by fields of concentration of oxygen O2 (fig.6), carbon monoxide CO (fig.7) and carbon dioxide CO2 (fig. 8).

In the model for combustion products formation three different reactions between char and flue gas are considered. The oxidation of the char to carbon monoxide or carbon dioxide and the reduction of carbon dioxide at the surface of the char particle to carbon monoxide.

The model incorporates the different effects of oxygen and carbon dioxide diffusion to the particle surface and in the pores and the kinetics of the chemical reaction at the surface as a function of temperature and particle diameter.

The Eddy Dissipation Model according to Magnusson et al. is used to predict the combustion of the volatiles and the carbon monoxide formed during char combustion. Gaseous fuels are treated like volatiles.

Due to the CO reactions also at lower temperatures CO concentration is further reduced in the gas path after the furnace outlet.

Conclusion. Results obtained by means of computer modeling of gas flows behavior, species concentrations, temperature fields due to combustion, radiation and convective heat transfer and the pollutant formation and destruction in furnace of real boiler PK39 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.

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ҚАЗАҚСТАНДАҒЫ ЖЭО ӨНДІРІСТІК ПЕШТЕРДЕГІ ЖЫЛУ ЖӘНЕ МАССААЛМАСУ ҮДЕРІСТЕРІН 3D МОДЕЛЬДЕУ

Бұл жұмыста FLOREAN бағдарламасы көмегімен Брауншвейг қаласы Техникалық университетінің жылутехникасы және жанармай технологиясы институтында өндірілген 3D модельдеу әдісі бойынша құйын тәріздес жанғышы бар пештердегі жылу мен массаалмасу үдерістері қарастырылған. Алынған нәтижелер CO, CO_2 және тағы басқа жану өнімдерінің концентрациясы, жылдамдығы және температурасы үшін жандыру үдерісін сипаттайды.

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3D-МОДЕЛИРОВАНИЕ ПРОЦЕССОВ ТЕПЛО- И МАССООБМЕНА В ПРОМЫШЛЕННЫХ ТОПКАХ ТЭЦ КАЗАХСТАНА

В настоящей работе методом 3D-моделирования при помощи программы FLOREAN, разработанной в Институте теплотехники и Топливных Технологий Технического Университета (г. Брауншвейг), рассмотрены процессы тепло- и массообмена в топках с вихревыми горелками . Полученные результаты описывают процессы сжигания для температуры, скорости и концентрации продуктов горения CO, CO_2 и т.д.