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MODERN COMPUTING EXPERIMENTS ON PULVERIZED COAL COMBUSTION PROCESSES IN BOILER FURNACES

Abstract. The aim of the work is to create new computer technologies for 3D modeling of heat and mass transfer processes in high-temperature physico-chemical-reactive environments that will allow to determine the aerodynamics of the flow, heat and mass transfer characteristics of technological processes occurring in the combustion chambers in the operating coal TPP RK. The novelty of the research lies in the use of the latest information technologies of 3D modeling, which will allow project participants to obtain new data on the complex processes of heat and mass transfer during the burning of pulverized coal in real combustion chambers operating in the CHP of RK. Numerical simulation, including thermodynamic, kinetic and three-dimensional computer simulation of heat and mass transfer processes when burning low-grade fuel, will allow finding optimal conditions for setting adequate physical, mathematical and chemical models of the technological process of combustion, as well as conduct a comprehensive study and thereby develop ways to optimize the process of ignition, gasification and burning high ash coals. The proposed methods of computer simulation are new and technically feasible when burning all types of coal used in pulverized coal-fired power plants around the world. The developed technologies will allow replacing or eliminating the conduct of expensive and labor-consuming natural experiments on coal-fired power plants.

Key words. Combustion, boundary conditions, computer simulation, low-grade coal, pulverized coal, reacting mixture, combustion chamber, numerical experiment.

Introduction

Kazakhstan is currently a developed country rich in natural resources. The fuel and energy complex is the basis for life support and economic development. Kazakhstan coal has high ash content (~ 40%) so they rated as low-grade, despite of it this organic fuel covers more than 40% of the demand for primary energy resources. The use of such quality coal leads to economic and ecological problems, related with ineffective incomplete combustion of fuel, which causes a high level of carbon and nitrogen compounds in the atmosphere.

In this regard, the President of the Republic Nazarbayev N.A. identified the global energy-environmental strategy for sustainable development of Kazakhstan, where he expressed ideas about sustainable energy. According to the adopted "Sustainable Energy Strategy for the Future of Kazakhstan until 2050" [1], the factors of energy independence and development principles include the requirements of ensuring the interests of the new generation and preserving the environment, which are determined by the following parameters: ensuring the world level of economic and technical efficiency throughout the country's energy sector; control the level of environmental impact of energy; the existence of an internal policy aimed at ensuring the availability of all types of energy; possession of the optimal institutional structure of the energy-complex; ensuring participation in international energy markets.

In the main, the country is currently dependent upon fossil fuels for power generation. As shown in Fig. 1 13% of Kazakhstan's power is generated by hydroelectric power plants, and whilst 90% is from thermal-powered plants (75% coal-fired stations).

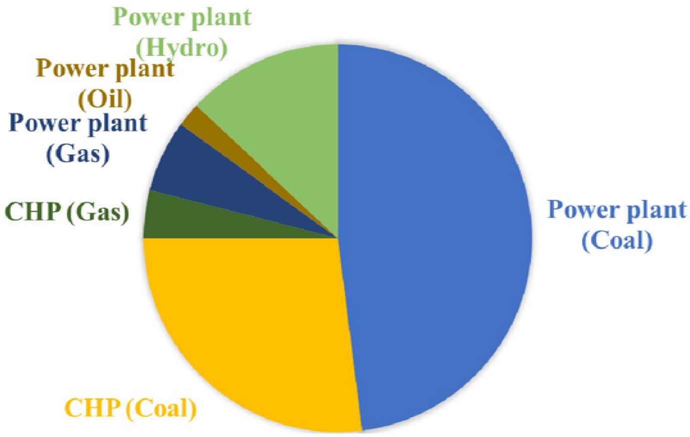

Fig 1 - Kazakhstan's electricity generating capacity (%)

To optimize the combustion of solid fuels, to develop and implement “clean” technologies and to protect the environment and ensure the efficiency of power plants, a deeper study of the issues of burning solid fuels in the combustion chambers of boilers and conducting research of technological processes taking place at TPPs is needed. It is possible with a combination of physical, scientific and applied, technological and engineering research in the field of optimization of solid fuel combustion processes [2-7]. In this regard, it becomes relevant to conduct computational experiments on the study of ignition, heat transfer, and mechanisms for burning out a coal-dust torch in the combustion chambers of boilers of energy facilities.

Methods of pulverized coal combustion research

At present, the intensive development of computer technologies and numerical simulation methods ensures a sufficiently high accuracy, the convergence of numerical results and their agreement with the results of field experiments. The use of computational fluid dynamics CFD allows one to obtain data without field experiments, which can then be used to substantiate the parameters and modes of thermal and hydrodynamic processes in the preparation of subsequent experimental studies on real energy facilities.

To study the complex physicochemical processes occurring while the pulverized coal combustion in furnace of boilers, it is necessary to have certain conditions required for carrying out computational experiments, including a multiprocessor computing system, an adequate physical, mathematical and chemical model and an exact method for solving a system of differential equations that describe the real technological process of burning pulverized coal in the existing power plant.

Numerical simulation uses numerical methods for solving the fundamental equations of heat and mass transfer processes using powerful computers. The theoretical analysis of vortex flows is based on the Navier-Stokes and Reynolds equations [8]. However, due to the nonlinearity and interconnectedness of these equations, their solution in the general case can be found only numerically [9]. The predominant method in the numerical simulation of subsonic currents and heat and mass transfer is the well-proven algorithm of SIMPLE Patankar-Spalding [10].

The description of the numerical model is based on a number of physical laws of conservation of mass, momentum, energy [11]. The mathematical model consists of a system of differential equations, algebraic closing relations and boundary (initial and boundary) conditions.

Since most practical flows are turbulent, the conservation equations must be considered in averaged and filtered by time or spatial forms, which must be closed using additional turbulent models [12]. For the formulation of a mathematical model, we consider the basic equations.

Since there are no sources of mass, only the transformation of the constituent components takes place. In this case, the equation of conservation of mass or the continuity equation takes the form (where the first term of the equation describes the flow nonstationarity, the second term is convective transport):

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \quad (1)$$

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i+F_i \quad (2)$$

The first term of the equation describes the nonstationarity of the flow, the second - convective transport, the third and fourth terms - surface forces (pressure gradient and molecular diffusion), the fifth - mass forces (gravity), the sixth - external mass forces.

The energy conservation equation takes into account energy transfer due to conductivity, diffusion, and viscous dissipation:

$$\frac{\partial(\rho h)}{\partial t}+\frac{\partial}{\partial x_i}(\rho h u_i)=\frac{\partial p}{\partial t}+u_i\frac{\partial p}{\partial x_i}-\frac{\partial}{\partial x_i}(k_{eff}\frac{\partial T}{\partial x_i})-\frac{\partial}{\partial x_{ij'}}h_{j'}J_{j'}+(\tau_{ij'})_{eff}\frac{\partial u_j}{\partial x_j}+S_h, \quad (3)$$

where $h=\sum_{j'} m_{j'}h_{j'}$ – enthalpy for ideal gases, $h=\sum_{j'} m_{j'}h_{j'}+p/\rho$ – enthalpy for incompressible flow of gas, $h_{j'}=\int_{T_{ref}}^{T} c_{p,j'}dT$ – enthalpy for flow $J_{j'}$ diffusion substance, $k_{eff}=k_l+k_t$ – effective thermal conductivity (the sum of laminar and turbulent thermal conductivity), $(\tau_{ij'})_{eff}$ – effective stress tensor, S_h – source term that takes heat into account due to chemical reactions and other volumetric energy sources (heat due to radiation, convective exchange between particles and the gas phase, and heat of combustion).

To study the turbulent burning flow of an industrial flame, the averaged conservation equations are used, supplemented by a two-parametric k-ε model of turbulence [13].

Simulation of the combustion process in the gas phase is a complex process involving numerous chemical reactions of fuel and oxidizer through the formation of intermediates and final products of combustion. The task is further complicated because of the interaction between turbulence and the kinetics of the combustion process, in view of the fact that turbulent reactive flows are characterized by sharp fluctuations in temperature and density, under the strong influence of exothermic reactions of the combustion process. To simulate the combustion of the gas phase, a simple chemical reaction system developed by Spalding is used. The model describes the global nature of the combustion process, where the complex mechanism of chemical kinetics is replaced by infinitely fast chemical reactions between fuel and oxidant [14].

So for mathematical modeling of processes occurring in combustion devices during coal combustion, the FLOREAN computer program [15-16] based on numerical solution of three-dimensional equations of energy and substance transfer taking into account chemical reactions is used. All mathematical models represent a complex system of nonlinear three-dimensional partial differential equations. They consist of the equations of continuity of the medium, the state of an ideal gas and the motion of a two-phase medium, heat transfer equations, chemical kinetics, and diffusion for the components of the reacting mixture, taking into account the radiative and turbulent transport described by the k-ε model of turbulence. For numerical calculation were used the primary and boundary conditions, also control volume method for solving the differential equations [17].

Setting of the computing experiments in boiler of RK

In the present work, for carrying out computational experiments on pulverized coal combustion used software package FLOREAN. Creating a database for modeling is carried out using the PREPROZ