ABSTRACT

of dissertation for the Philosophy Doctor (PhD) degree at specialty «6D072300 – Technical Physics» Nugymanova Aizhan Olzhabekkyzy on the topic «**Combustion processes in furnace chambers of Kazakhstan TPPs using high-ash coal**»

The dissertation work is devoted to the study of the processes of heat and mass transfer and the formation of harmful substances during the combustion of low-grade fuel in the combustion chamber of the BKZ-75 boiler at the Shakhtinskaya TPP. Physicomathematical, chemical and geometric models have been developed, which correctly describe real combustion processes. Computational experiments were carried out to study the influence of the introduction of the technology of two-stage combustion of high-ash Karaganda coal, the design parameters of the combustion chamber, various layout solutions for burners and the method of supplying a fuel air mixture on the main characteristics of heat and mass transfer processes: flow aerodynamics, temperature distribution and concentration of combustion products. With the help of modern computer technologies, a highly informative 3D visualization of the results obtained is presented and compared with experimental data obtained directly at the kazakh TPP.

Relevance of the topic. Thermal power engineering is the leading branch of the world energy sector and plays a major role in the development of industry in many countries of the world, but it exceeds all other industries in terms of emissions of pollutants into the atmosphere (ash particles, sulfur dioxide, nitrogen and carbon oxides, etc.). In the furnaces of power boilers, the combustion of various fuels is used, and in particular solid ones: lignite, coal, coke.

The environmental situation in the world and the desire for clean air in cities have forced many developed countries to close coal plants. At the same time, traditional cheap coal energy is successfully operating in developing countries, new environmentally friendly coal technologies are being created and introduced.

Recent events in the world have shown that energy sources such as wind and sun, which are characterized by inconstancy (windless and cold weather), may not be enough to provide the world with electricity and heat. Currently, Europe, leading the "green" revolution, is forced to increase its consumption of coal and convert gas stations to coal today. Thus, although in the future the share of coal-fired power plants in the world will steadily decrease, coal will remain one of the main types of fuel in the thermal power industry.

Kazakhstan possesses huge reserves of hydrocarbons: 33.600 million tons of coal – 3.8% of world reserves, 30.000 million barrels of oil - 1.8% of world reserves and 1.5 trillion cubic meters of natural gas – 0.8% of world reserves, which have a significant impact on the formation and state of the world energy market. The main fuel of Kazakhstan thermal power plants, generating up to 85% of electricity, is coal (ash content of up to 40–50%), the use of which leads to problems in flame stabilization, slagging of convective heating surfaces, air pollution with fly ash, carbon and nitrogen oxides, hydrocarbons and other combustion products.

In most regions of the Republic of Kazakhstan, the ecological situation is not

only unfavorable, but also catastrophic. According to the latest data provided by the energy agency, Kazakhstan carries out 43.7% of pollutant emissions into the atmospheric air of Central Asia, and CO_2 emissions reached 12.8 tons per capita.

For the significant economic development of Kazakhstan and the associated growth in demand for electricity, it is necessary to fundamentally modernize existing energy facilities and build new ones. Of course, if possible, you need to change the type of main fuel and move from coal to gas, which will significantly reduce emissions of pollutants into the atmosphere.

It is theoretically possible to convert a coal-fired TPP to gas, but a number of problems arise that slow down this process: Kazakhstan coal (Ekibastuz, Karaganda, Turgai coal basins) has a number of advantages – low sulfur content and high volatiles yield to dry ashless mass. The reserves of inexpensive coal fuel are sufficient and it is estimated that it will last for hundreds of years, while the reserves of oil and gas are limited. The transition from coal to gas will require the construction of new TPP plants or huge capital expenditures for the modernization and re-equipment of existing power boilers.

Although in the future the share of coal-fired plants will decrease, coal will still remain the main type of fuel for the Kazakh thermal power industry. To reduce the dependence of the energy balance on coal combustion, a National Project for the Development of the Electric Power Industry will be developed, according to which Kazakhstan will completely abandon the use of coal by 2060. In this regard, in the context of tightening environmental requirements, one of the urgent tasks of modern domestic heat power engineering is the introduction of energy efficient environmentally friendly technologies at Kazakhstan coal-fired TPPs, with the help of which it is possible to control the formation of harmful substances and propose methods to reduce their emissions into the atmosphere.

The key to the further development of the republican fuel and energy complex of the country, along with innovative coal developments, are also information technologies, which are currently used in the heat power industry of developed countries. The introduction of modern energy technologies is determined by the level of development of methods for calculating the corresponding physicochemical processes occurring during fuel combustion in the combustion chambers of a TPP, with theoretical and experimental studies of the processes of movement and heating of fuel particles, their subsequent transformations in the combustion space and the formation of harmful dust and gas emissions.

Recently, computer technologies based on modeling the processes of heat and mass transfer during fuel combustion in the furnaces of power boilers have become widespread. Computer technologies make it possible to carry out computational experiments and obtain results that are in good agreement with experimental data obtained directly at an operating power facility.

Purpose of work: To introduce the method of two-stage combustion of high-ash Kazakh coal, effective design and layout solutions for burners using 3D computer modeling methods, study the processes of heat and mass transfer and the formation of harmful substances in the combustion chamber of the BKZ-75 boiler of the operating Shakhtinskaya TPP and propose optimal options for minimizing

emissions of carbon and nitrogen oxides into the atmosphere.

Research objectives. In accordance with this goal, the main objectives of the study are:

- to carry out computational experiments, **develop** physical, mathematical, chemical and geometric models that correctly describe the actual technological processes of combustion of low-grade coal in the combustion chamber of the BKZ-75 boiler at Shakhtinskaya TPP;
- **to carry out** computational experiments to study the effect of various methods of fuel injection (direct-flow and vortex with a swirl angle of a pulverized coal flow) through burners on combustion processes and to determine the optimal option for feeding air mixture into the combustion chamber;
- to optimize the combustion process, **carry out** computational experiments to study aerodynamic, thermal and concentration fields in the combustion chamber of the BKZ-75 boiler during the forced partial shutdown of coal dust input through separate burners;
- **to carry out** computational experiments to study the influence of the technology of two-stage combustion of high-ash Karaganda coal on the characteristics of combustion processes and to determine the optimal option for supplying additional air to effectively reduce the level of harmful emissions;
- **to obtain,** using modern computer technologies, a highly informative 3D visualization of the results obtained and to verify them by comparing them with the available experimental data obtained directly at the TPP.

Object of study: combustion chamber of the BKZ-75 boiler of the operating Shakhtinskaya TPP (Shakhtinsk, Kazakhstan).

The subject of the research is the processes of heat and mass transfer and the formation of harmful substances during the combustion of high-ash Karaganda coal (ash content 35.1%) in the combustion chamber of the boiler of the Kazakh TPP.

Research methods.

To study the processes of heat and mass transfer in combustion chambers in order to develop environmentally friendly coal technologies, numerical methods were used and computational experiments were carried out. Their use makes it possible to achieve geometric and physical similarity of the objects under study, compliance with all basic parameters and operating conditions that are adequate to the technological scheme of fuel combustion at a real energy facility.

The novelty of the dissertation research:

- the effect of swirling a pulverized coal flow on the characteristics of heat and mass transfer processes (vector of total velocity, temperature distribution, concentration of combustion products) has been investigated;
- investigated the main characteristics of combustion processes at a reduced boiler load;
- various modes of additional air supply to the combustion chamber through OFA-injectors have been investigated: 0% (basic version), 5%, 10%, 15%, 18%, 20%, 25% and 30% of the total air volume.

The main provisions for the defense:

1 When using vortex burners with swirling the air mixture flow and tilting

them to the center of symmetry of the BKZ-75 boiler by 30 degrees, the average concentrations of carbon monoxide CO and nitrogen dioxide NO_2 at the outlet from the combustion chamber decrease by 15 and 20%, respectively.

2 The use of vortex burners in the mode of reducing the boiler load leads to a decrease in the values of the concentrations of harmful substances (carbon monoxide CO and nitrogen dioxide NO_2) at the outlet from the combustion space by 34 and 8%, respectively.

3 When using the technology of two-stage fuel combustion in the BKZ-75 boiler, the optimal option for reducing the concentration of carbon monoxide CO by 36% and nitrogen dioxide NO_2 by 25% at the outlet from the furnace is to use OFA-injectors with 18% of the total air volume supplied through them.

Theoretical and practical significance of the results

Theoretical significance research consists in obtaining fundamental knowledge that can be applied to build a modern theory of combustion of various types of fuel and its rational use. The developed modeling methods for conducting computational experiments and highly informative 3D visualization of research results will contribute to the development of computational fluid dynamics, mathematical, numerical and computer modeling.

The results of the study of combustion processes with the aim of introducing environmentally "clean" energy technologies at coal-fired TPPs are of **practical importance** since they will contribute to solving urgent problems of heat power engineering and ecology. The results obtained make it possible to effectively control the combustion of fuel in real power plants with the necessary impact on its various parameters and give recommendations for optimizing the combustion of energy fuels and minimizing harmful dust and gas emissions. Interested parties may be operating coal-fired TPPs in Kazakhstan and countries with traditional coal energy (Russia, China, India, etc.).

Personal contribution of the author. The author took part in all the main stages of research work: setting the research problem, choosing the object of research, developing models for the combustion of high-ash fuel and analyzing the results. I independently conducted computational experiments and used the 3D visualization method for graphical interpretation of the results.

Publications

Based on the materials of the dissertation, 27 scientific works (18 articles, 9 theses) were published, including 10 articles in journals indexed by Scopus and Web of Science, and 8 - in publications recommended by the Committee for Supervision of Education and Science RK.

Approbation of work.

The presented research results, in this work, were discussed at the following international conferences: The International Congress of Chemical and Process Engineering (Prague); «Фараби әлемі»; First International Alternative Energy Sources, Materials & Technologies (Bulgaria); International Academic Conferences: Engineering (Prague); X Всероссийская конференция с международным участием «Горение топлива: теория, эксперимент, приложения» (Novosibirsk); First Annual Meeting of Kazakh Physical Society

Nazarbayev University (Nur-Sultan).

Reliability and validity of the results obtained are provided by the use of fundamental physical laws, a thorough analysis of the implemented empirical models, the use of modern numerical methods, comparison of the results with the available calculated and experimental data obtained in the course of field measurements at an operating energy facility.

Connection of the topic with the plans of scientific works. The dissertation work was carried out within the framework of the scientific projects: "Optimization of combustion processes of high-ash coal in power boilers of thermal power plants of Kazakhstan to reduce emissions of harmful substances into the atmosphere" and "Implementation of OFA-Technology in order to minimize harmful dust and gas emissions at Kazakhstan thermal power plants using high-ash coal", under the grant financing for scientific and scientific-technical projects of the Ministry of Education and Science of the Republic of Kazakhstan in the priority area 1. Energy and mechanical engineering. Specialized scientific direction: 1.1 Heat and electricity and the impact of the energy sector on the environment, energy saving.

Volume and structure of the thesis. The dissertation consists of an introduction, six chapters, a conclusion, and a list of references. The volume of the thesis is 123 pages, includes 67 figures, 14 tables.