Implementation of New Technologies to Optimize Fuel Combustion Processes and Reduce Emissions of Harmful Substances

A.S. Askarova[1-2], A. Georgiev[3], A. Bolegenova[1-2], V. Yu. Maximov[1], A. Bolegenova[2], A.O. Nugymanova[1], B. Mamedov[1]*

[1]Al-Farabi Kazakh National University, Dept. of Physics and Technology, 71a, Al-Farabi ave, 050040 Almaty, Kazakhstan

[2] Science Research Institute of Experimental and Theoretical Physics al-Faraby Kazakh National University Republic of Kazakhstan, al-Farabi Kazakh National university, 050040, al-Farabi Ave. 71, Almaty, Republic of Kazakhstan

[3]Department of Mechanics, TU of Sofia, branch Plovdiv, Bulgaria

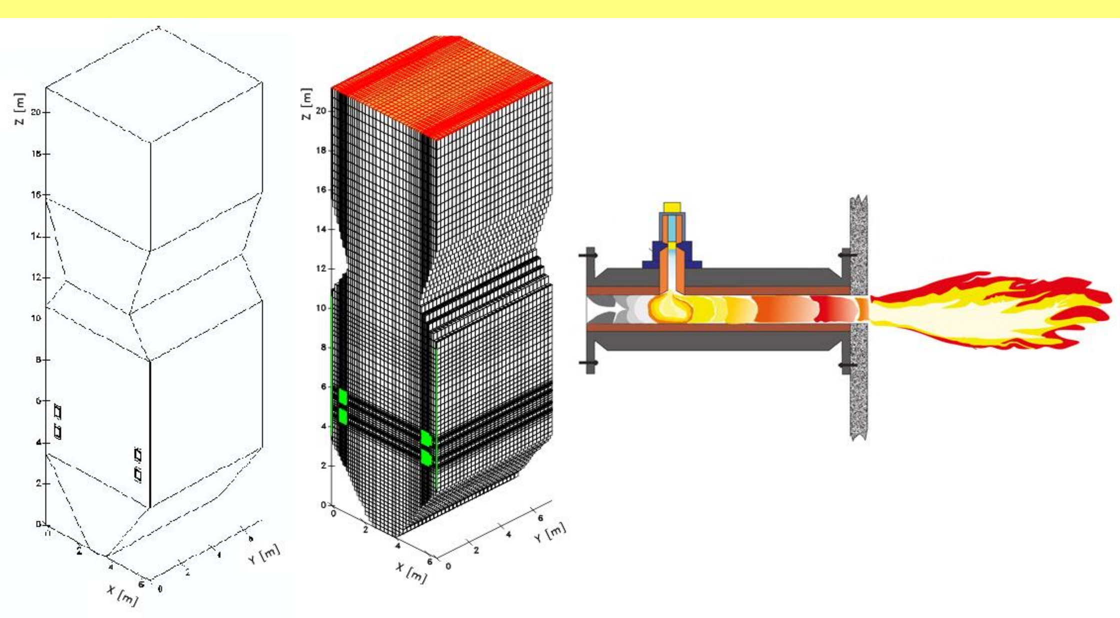
Introduction

The world's leading countries are striving to increase the use of renewable energy sources (RES), but the industrial economy is still heavily dependent on fossil fuels - coal, oil and gas. Recent events in the world have shown that energy sources such as wind and sun, which are characterized by volatility (calm and cold weather), may not be enough to provide the world with electricity and heat. In countries rich in natural resources, renewable energy is still losing competition to traditional types of generation. In this regard, in order to increase the efficiency of using traditional fuel, various methods of its ecological and efficient combustion are being developed. So, to reduce emissions of harmful substances, a plasma technology for ignition and thermochemical fuel preparation has been developed.

This article proposes the introduction of modern technology for plasma ignition and stabilization of a pulverized coal flame at existing power facilities. Numerical studies of physical and chemical processes occurring during the combustion of thermochemical prepared pulverized coal flows in areas of real geometry (combustion chambers of thermal power plants) have been carried out. The latest information technologies and 3D computer modeling methods were used to study furnace processes and graphical interpretation of the results obtained [2–4].In the study of heat and mass transfer processes in the furnace chamber in order to develop an environmentally "clean" coal technologies, the role of numerical methods and carrying out computational experiments. Their use allows to achieve the geometrical and physical similarity of the objects, complying with all the basic parameters and operating conditions, adequate technological scheme of fuel combustion on the real energy facility.

The object of calculations

For numerical experiments, the combustion chamber of the BKZ-160 boiler of the operating Kazakh thermal power plant was chosen. The BKZ-160 boiler with a steam capacity of 160 t/h is equipped with burners with tangential fuel supply. On the sides of the combustion chamber there are four blocks of direct-flow slot burners directed tangentially to a circle with a diameter of 0.78 m (Fig. 1). Each burner has one air mixture channel and two secondary air channels located above and below the air mixture channel and separated by lined walls.



a) b) c)

Figure 1 General view of the combustion chamber of the BKZ-160 boiler (a) equipped with plasma torches, their breakdown into control volumes (b) and the scheme of using the plasma torch in the burner (c)

The initial data for carrying out numerical modeling and performing numerical experiments on fuel combustion in the combustion chamber of the BKZ-160 boiler

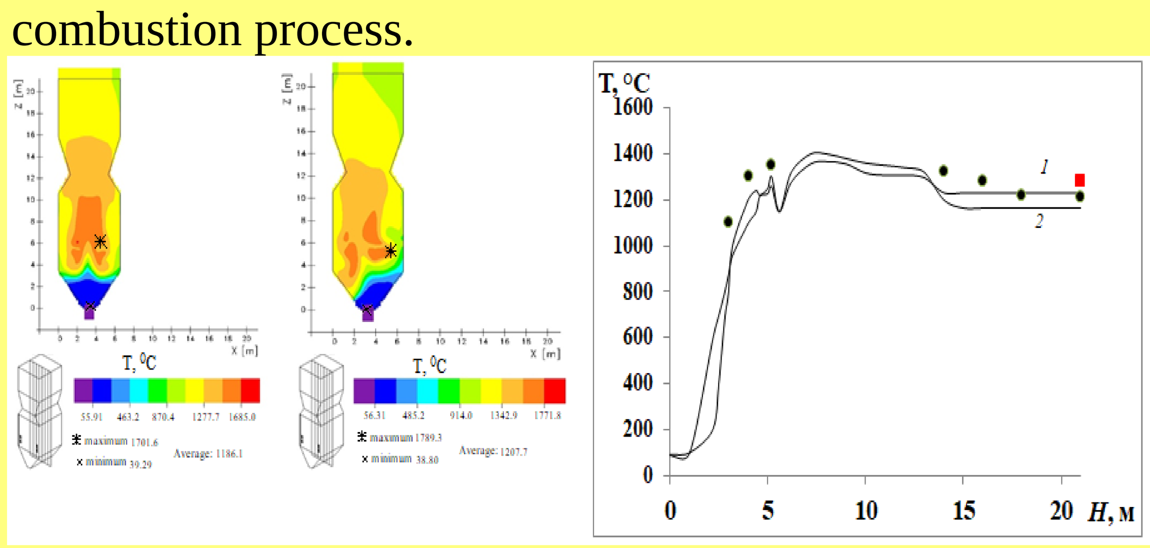
The plasmatron (Fig. 1c) is installed on the lined channel of the burner air mixture, which is thereby converted into a PFS and installed directly into the furnace chamber. The air mixture entering the burner interacts with the plasma jet flowing out of the plasma torch nozzle. The average temperature of the plasma jet is about 5000^{o}C depending on the electrical power of the plasma torch and plasma air flow.

In accordance with the given geometry of the boiler, a finite-difference grid was created for numerical simulation, which for the studied combustion chamber has steps along the X, Y, Z axes: 59 × 32 × 94, which is 177 472 control volumes (Fig. 1b)

As a result of the computational experiments, the aerodynamics of the flow, temperature fields and fields of concentrations of carbon oxides CO and nitrogen NO were obtained throughout the volume of the combustion chamber and at the exit from it.

Result

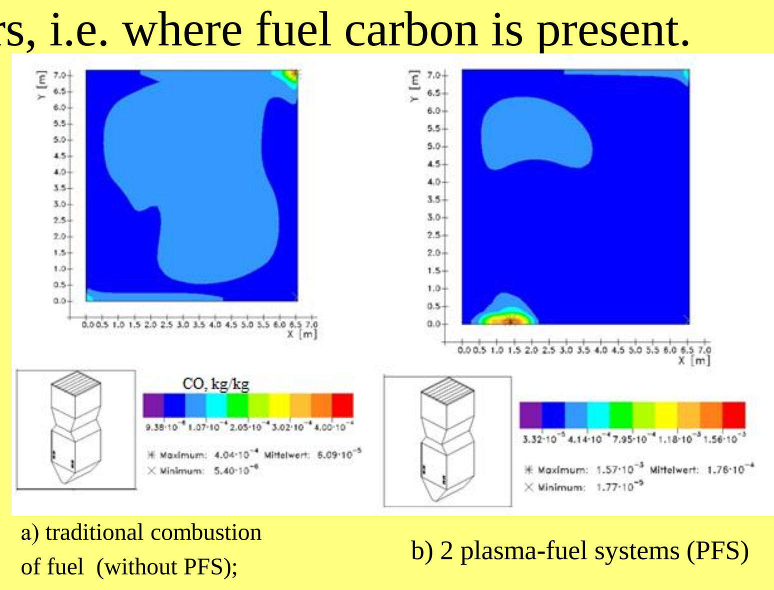
Figure 2 shows a three-dimensional distribution in the longitudinal section and a two-dimensional distribution along the height of the combustion chamber of the average temperature values T for the boiler under study. A comparative analysis of the distribution of the average temperature in the cross section for the studied modes is carried out: when ordinary fuel and fuel that has undergone thermochemical plasma preparation enters the combustion chamber. At the same time, during plasma treatment of fuel, a shift in the location of the flame core and an increase in the length of the zone of maximum temperatures are observed. The increase in the temperature of the torch during the combustion of 2 activated streams occurs faster. The temperature values differ to a greater extent in the burner zone. The minima on the curves are related to the low temperature of the air mixture entering the combustion chamber through burners not equipped with plasma systems. When the combustion chamber is fully equipped with plasmatrons (Figure 2c, curve 1-2), there are no sharp temperature drops along the entire height of the combustion chamber, which indicates the stability of the combustion process.



a) traditional combustion of fuel (without PFS); b) 2 plasma-fuel systems (PFS) c) 1 — traditional combustion of fuel, 2 — 2 plasma-fuel systems, ■ — calculation results [1], ● — experimental data [2-3]

Figure 2 - Temperature distribution in the longitudinal section (a,b) and in height (c) of the combustion chamber of the BKZ-160 boiler

Figure 3 illustrates the distribution of average values of carbon monoxide (CO) for the BKZ-160 boiler, three-dimensional in the exit and two-dimensional along the height of the combustion chamber, and a comparative analysis was carried out for various options for the implementation of plasma-fuel systems. Analysis of Figure 3 shows that carbon monoxide is mainly concentrated in the zone of propagation of fuel jets from burners, i.e. where fuel carbon is present.

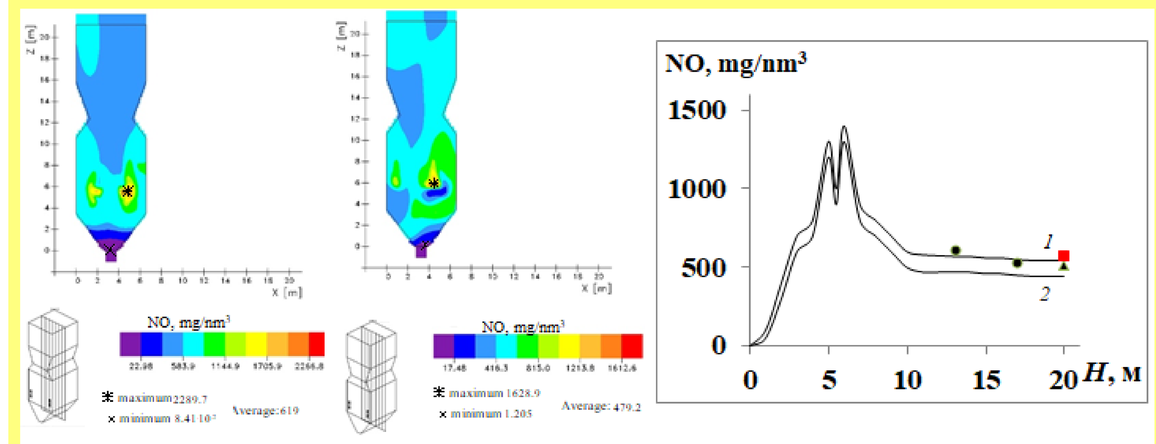


a) traditional combustion of fuel (without PFS); b) 2 plasma-fuel systems (PFS)

Figure 3 - Distribution of the carbon monoxide in the exit (a,b) and in height (c) of the combustion chamber of the BKZ-160 boiler

With the introduction of plasma-activated flows for the BKZ-160 boiler, due to an increase in the CO content in the incoming highly reactive two-component flow, maximum CO values are observed in the cross-sectional plane of the burners. At the output, the amount of CO decreases. This can be explained by an increase in the content of carbon monoxide in the highly reactive two-component fuel that has passed PFS entering the combustion chamber.

At the same time, the concentration of CO at the outlet of the combustion chamber decreases with an increase in the number of PFS. The values of the average concentration of nitrogen oxides at the outlet of the combustion chamber of the BKZ-160 boiler are shown in Table 1.



a) traditional combustion of fuel (without PFS); b) 2 plasma-fuel systems (PFS) c) 1 — traditional combustion of fuel, 2 — 2 plasma-fuel systems, ■ — calculation results [1], ● — experimental data [2-3].

Figure 4 - Distribution of the concentration of nitrogen oxide NO in the longitudinal section (a,b) and in height (c) of the combustion chamber of the BKZ-160 boiler

The main gas formation of NO occurs in the area of distribution of flows from the burners. At the same time, the nature of the distribution of curves in this region is ambiguous, which indicates a complex process of the formation of nitrogen oxides in this region and the effect of plasma activation on the formation of NO.

We see that the use of plasma burners leads to a decrease in the total concentration of NO at the outlet of the furnace space (Figure 4c, curves 1-2).The maximum allowable concentration (MPC) for nitrogen oxides NO, adopted in the Republic of Kazakhstan by 2020, is 850 mg/Nm3. Thus, we can conclude that the installation of plasma fuel systems (PFS) in the combustion chambers of power boilers significantly improves the environmental performance of TPPs.

The values of the average concentration of nitrogen oxides at the outlet of the combustion chambers for the boiler under study are given in Table 1.

Table 1 - Values of the main characteristics of the heat and mass transfer process (temperature T, concentrations of CO and NO) at the outlet of the combustion chamber of the BKZ-160 boiler at Almaty CHP-2

Main characteristics of the heat and mass transfer process	Traditional combustion of fuel (without PFS)	2 plasma-fuel systems (PFS)
Temperature T, ^{0}C	1092	1080
Carbon oxide, kg/kg	0,00061	0,00017
Nitrogen oxide, mg/nm^3	520	444,52

Conclusions

Based on the results of the research, we formulate the following conclusions:

A physical and mathematical model has been obtained that describes the processes of heat and mass transfer during the combustion of solid fuel, which is modified and adapted to the combustion of a thermochemically activated and gasified pulverized coal flame.

It has been established that the method of thermochemical activation of pulverized coal flows makes it possible to significantly optimize the combustion process of low-grade high-ash coals and significantly reduce emissions of harmful both gaseous and solid substances.

Satisfactory agreement between the experimental and calculated data allows us to conclude that the mathematical model proposed in this work is applicable for calculating high-temperature flows with chemical reactions in regions of real geometry, both for conventional combustion and for the combustion of plasma-activated pulverized coal flows.

References

[1] Askarova A.S., Safarik P., Bolegenova S.A, et al. Numerical investigation of heat and mass transfer processes in the combustion chamber of industrial power plant boiler. Part 1 flow field, temperature distribution, chemical energy distribution. J. Applied and Computational Mechanics, 11-2, 115-128, (2017).

[2] Aliyarov B.K. Mastering the combustion of Ekibastuz coal at thermal power plants. - Almaty: Gylym, 1996. - 272 p.

[3] Alijarov B.K. , and Alijarova M.B. Combustion of Kazakh coals in thermal power stations and large-power boiler houses, Almaty, (2012).