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To cite this article: V E Messerle *et al* 2019 *J. Phys.: Conf. Ser.* **1261** 012022

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3D-modelling of Kazakhstan low-grade coal burning in power boilers of thermal power plant with application of plasma gasification and stabilization technologies

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Abstract. In this article, a study of the processes of heat and mass transfer in high-temperature and thermochemically activated reacting flows in a real physicochemical system (turbulent flows with physicochemical transformations in combustion chambers) in three-dimensional geometry using numerical methods was carried out. As a result of computational experiments vector distribution full velocity, temperature fields, fields of concentrations of nitrogen oxides NO over the entire volume of the combustion chamber were obtained and a comparative analysis was carried out for the two boilers. The results obtained allow us to conclude that the use of plasma preparation of a pulverized coal torch for combustion has a positive effect on the process of heat and mass transfer and allows minimizing emissions of harmful substances.

1. Introduction

At the present stage of development the industry of the Republic Kazakhstan, the question of increasing the efficiency of processes of to the production of energy is acute, while observing strict emission standards of harmful substances and economical use of equipment and fuel [1]. One of perspective decisions in the given area is thermochemical activation [2-5] of a coal dust. Realization of the advanced technologies of thermochemical activation and development of a method of calculation of such currents are associated with settlement-theoretical and experimental researches on thermophysical processes traffic and heating fuel particles, thermochemical process in plasmotrones and subsequent physicochemical transformations occurring in the combustion space.

With the use of plasma activation of pulverized coal, the input parameters used in the calculations are significantly different from those used in practice in the organization of combustion without plasma systems. The flame of the reacting fuel mixture enters the combustion chamber, which can cause changes in the main parameters of the combustion process [6-8]. In this regard, the complex study of the working process of the combustion chamber taking into account the influence of thermochemical preparation of fuel, including numerical modeling of the processes occurring in the volume of the combustion chamber, is of particular relevance [5-6].



In this article, a physico-mathematical model and 3D computer simulation are used, which allow describing the processes of heat and mass transfer in high-temperature [9-12] and thermochemically activated pulverized coal with high accuracy.

In the article, new and technically feasible technologies applying plasma chemical treatment of solid fuels, which can be applied in pulverized coal-fired thermal power plants, are proposed based on a computer simulation of the fuel combustion. The plasma technology allows to exclude expensive and scarce fuel oil and natural gas from the balance of thermal power plants, which are traditionally used to kindle boilers and stabilize the combustion of a pulverized coal torch. Three-dimensional computer simulation of furnace [13-14] processes allows to optimize the process of ignition, gasification and combustion of coal, including low-grade coal (high-ash).

2. Materials and methodology

The process of plasma thermochemical preparation of fuel for combustion is carried out in the plasma-fuel system (PFS). The plasmatron is installed on the lined channel of the burner's air mixture, which is thereby converted into PFS [2-5] and installed directly into the combustion chamber.

Plasma thermochemical preparation of coal for combustion consists in heating by a plasma torch with an oxygen deficit in the stream of a pulverized coal mixture in the special chamber up to the temperature exceeding temperature of self-ignition of the given coal. The aero-mixture entering the burner interacts with the plasma stream flowing from the nozzle of the plasmatron. The average temperature of the plasma stream is about 5000°C, depending on the electric power of the plasmatron and the consumption of plasma-forming air. At the same time, there is almost a complete output of volatile substances and partial combustion and gasification of carbon of coal. As a result, the obtained fuel mixture, consisting of fuel gas and coke residue, ignites when mixed with secondary air and burns steadily even in the cold furnace without using the reserve high-reaction fuel (fuel oil or natural gas) in order to stabilize the pulverized coal torch.

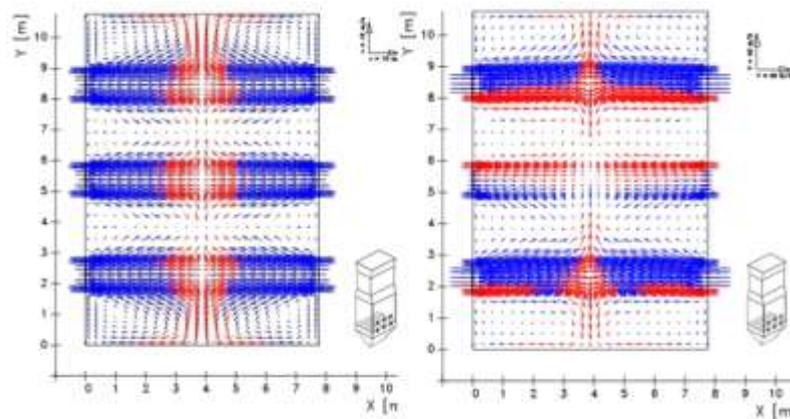
3. Results and discussion

This paper presents the results of 3D computer simulation of heat and mass transfer processes and the influence of thermochemical activation of pulverized coal flows on the combustion process of a pulverized coal flame in the combustion chambers of the PK-39 boiler of the Aksu TPP and BKZ-160 Almaty CHP-3 [15-19].

As a result of the computational experiments, the distributions of the full velocity vector, temperature fields, fields of nitrogen oxide NO concentrations over the entire volume of the combustion chambers were obtained and comparative analysis for two of the investigated boilers.

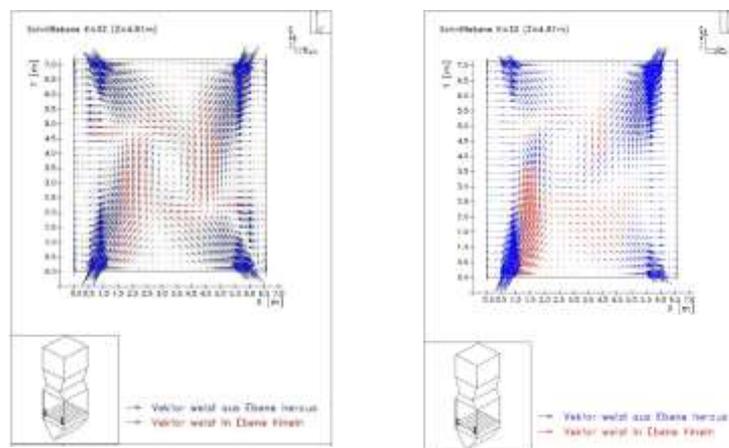
Figures 1-2 show the full velocity vector field in the combustion chambers in the burner belt area for each of the PK-39 and BKZ-160 boilers.

Analysis of Figure 1 shows that in thermochemically activated flows (4 plasma burners); the core of the torch is shifted to the center of symmetry of the combustion chamber of the boiler PK-39. At the point of impact of the oncoming flows as a result of braking, the dynamic pressure is transformed into static pressure. Under the action of the resulting pressure drop, the total flow spreads up and down with increased velocities. When impact flares collide and the turbulence of the streams, mass and heat transfer are accelerated to a large extent, while the mixture formation and heating amplify the process of combustion.



a) traditional combustion of fuel (without PFS); b) combustion of thermochemically activated fuel (4 PFS)

Figure 1. The field of the full velocity vector in the section of burners of the combustion chamber of boiler PK-39 of Aksu TPP.

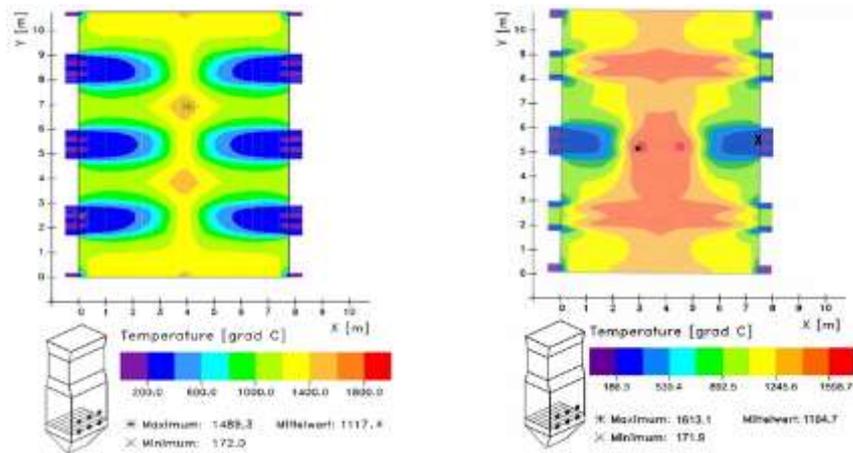


a) traditional combustion of fuel (without PFS); b) combustion of thermochemically activated fuel (2 PFS).

Figure 2. Distribution of the full velocity vector in the area of burners of the combustion chamber of the boiler BKZ-160 of Almaty CHP-3.

An analysis of Figure 2 indicates a significant difference between the two investigated cases for the boiler BKZ-160. Figure 2 b) clearly shows the flows of the pulverized coal mixture entering the furnace through conventional burners and through plasma-fuel systems. In the volume of the combustion chamber BKZ-160, the flows of the two-component high-reaction fuel gasified by plasma activation are propagated in accordance with the laws of aerodynamics and are the thermal source for the air mixture delivered through burners not equipped with plasma ignition systems.

Figure 3 for the boiler PK-39 illustrates the temperature fields in the cross section of lower layer of burners. We see a significant difference for the two cases. Compared with the use of conventional pulverized coal flow, the average temperature in the plane of the burner section for the boiler PK-39 with thermochemically activated flows increases and is 1117.4°C without activation; and with four activated flows - 1184.7°C.

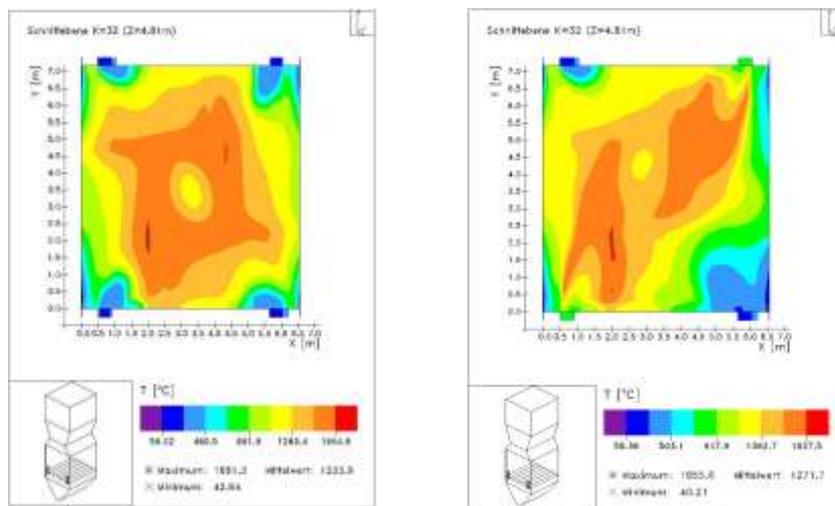


a) traditional combustion of fuel (without PFS);

b) combustion of thermochemically activated fuel (4 PFS).

Figure 3. The temperature field in the plane of the burner section of the lower tier of the furnace chamber of boiler PK-39 of Aksu TPP.

Analysis of Figure 4 for the BKZ-160 boiler also shows that, compared to conventional pulverized coal, the average temperature in the cross-section plane of the section of burners with thermochemical activated flows increases and amounts to: without activation - 1233.9 °C and with two activated flows in the lower stage of the burners - 1271.7 °C. On the basis of the foregoing, it can be concluded that for all the boilers under study the process of plasma activation of the combustion of an air mixture leads to an increase in the temperature in the area of installation of burner devices. At the same time, with an increase in the number of installed plasma-fuel systems, the combustion front is shifted to the location of plasma activation systems of coal flows.



a) traditional combustion of fuel (without PFS);

b) combustion of thermochemically activated fuel (2 PFS).

Figure 4. The temperature field in the plane of the burner section of the lower tier of the furnace chamber of boiler BKZ-160 of Almaty CHP-3

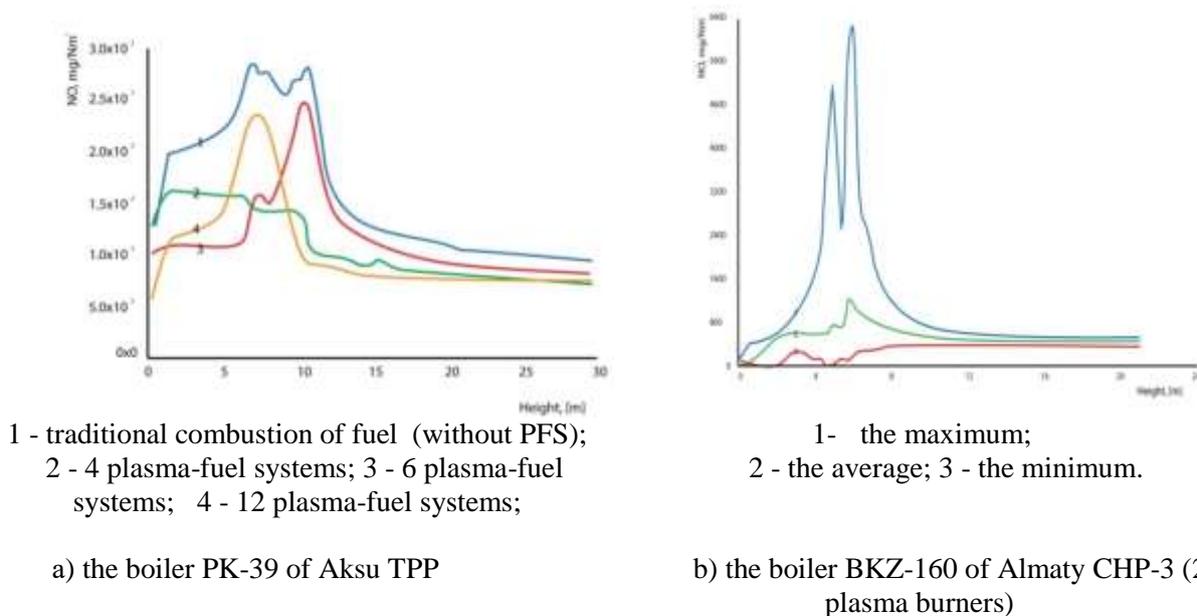


Figure 5. Distribution of nitrogen oxides concentration NO according to the height of combustion chambers of boilers PK-39, BKZ-160

Figure 5 shows the concentration fields of carbon oxides NO in the height of the combustion chamber and a comparative analysis for the three boilers under study. It can be seen from the Figure 7 that the main formation of nitrogen oxide NO_x occurs in the region of the burners. In this case, the behavior of the NO curves in this area is ambiguous, which indicates a complex nonlinear character of the process of formation of nitrogen oxides in this area and the undoubted influence of plasma activation on the process of their formation.

We see that the use of plasma burners leads to a decrease in the total concentration of NO from the combustion chamber and is: for the boiler PK-39 of Aksu TPP - for conventional combustion 932 mg/Nm³, and for 4 plasma burners 785 mg/Nm³; for the boiler BKZ-160 Almaty CHP-3 - 2 at the plasma burners - 444.5 mg/Nm³. The maximum permissible concentration for nitrogen oxides NO, adopted in the Republic of Kazakhstan by 2016 is 850 mg/Nm³. Thus, it can be concluded that the installation of plasma-fuel systems (PFS) in combustion chambers of power boilers significantly improves the environmental performance of TPPs.

4. Conclusions

The following conclusions can be made from the research:

- Theoretical numerical studies of fast-flowing physicochemical processes occurring during the burning of pulverized coal flows in real geometry areas have been performed. Physico-mathematical model describing the processes of heat and mass transfer in physical-chemical reacting flows, which is modified and adapted to the combustion of a thermochemically activated and gasified pulverized coal torch has been developed.
- The main regularities of the influence of thermochemical activation of turbulent flows with chemical reactions on the processes of heat and mass transfer in areas of real geometry have been identified and investigated. The use of plasma preparation of pulverized coal torch for combustion has a positive effect on the process of heat and mass transfer. The positive effect of thermochemical activation processes occurring during combustion of a pulverized coal flow in the first place is to increase the reactivity of such flows due to the most complete extraction of volatiles from coal and the partial gasification of the coke residue before entering the combustion chamber. Due to the presence of

charged particles in the plasma flow and superfast heating of coal particles, there is an increase in the rates of combustion reactions, including in the combustion space.

– Carried out researches of thermochemical plasma activation systems for pulverized coal have shown the possibility and effectiveness of their use in real heat and power facilities. It allows to solve economic problems: decrease in consumption of fuel oil, savings of fuel due to reduction mechanical burn; and ecological problems: decrease in harmful dust and gas emissions, which are typical when solid low-grade coal fuels from Kazakhstan deposits are burned at TPPs.

Acknowledgement

The study of the installation for coal combustion was carried out under state contract with IT SB RAS (AAAA-A17-117030910025-7), the plasma chemical processing of solid fuels and computer simulations was supported by the Ministry of Education and Science of the Republic of Kazakhstan (grants AP05132988 and AP05133590 and BR05236730).

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