

IRSTI 30.51.23; 30.17.35; 28.17.23

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Combustion processes in furnace chambers of Kazakhstan TPPs using high-ash coal

Abstract. In this article, carried out computational experiments to study the aerodynamic, thermal and concentration characteristics in combustion chamber of the boiler BKZ-420 Almaty TPP-2. Combustion chamber BKZ-420 has a significant drawback, which is that of a jet of hot air hitting the wall that is opposite the burners. This leads to her firing and a further violation of integrity. On the Almaty CHP-2 in the basic mode using this wall served cold the air mass flow 5 kg/s. In this paper, we proposed a new flow mode, which allows you to protect the wall from overheating, to reduce the temperature of the incoming flow more cold air. Carried out researches have allowed to conclude that the proposed regime provides not only protection against overheating of the boiler walls, but also reduces the concentration of harmful emissions. As a result of computer experiments were obtained fields of velocity, temperature, concentrations of harmful dust and gas emissions (CO, CO₂, NO₂) formed in combustion of solid fuels for different layout options holes and speed boost-extra air (5kg/s and 10 kg/s).

Key words: numerical simulation, combustion chamber, temperature, air velocity, carbon dioxide, nitrogen dioxide.

Introduction

The main consumer of primary energy resources in Kazakhstan is the electricity and heat generation sector (about 50% of consumed fuel). The total capacity of power generating sources in the RK is more than 18 thousand MW. The basis of generating capacity is thermal power plants – about 87%. The main type of fuel and energy resources in Kazakhstan is coal, the supply of which is mainly from the Ekibastuz field. Burning fossil fuels to produce electrical energy and heat, especially the power industry, with its huge centralized power plants, is one of the foundations of the functioning of a modern society and economy. On the other hand, fuel-burning installations consume large amounts of fossil fuel of different types, converting them into useful energy. The functioning of these enterprises leads to the formation of a variety of waste and delivery of large quantities of contaminants in all natural environments.

In recent decades, the rapid growth in computing power and the continuous improvement of numerical

algorithms has led to the extension of the range of applications available for study by computational methods. This increases the requirements to the mathematical models describing a certain class of application tasks, and accuracy of numerical methods for their implementation.

Relevant in the present time is the study of heat and mass transfer processes in industrial power plants, in particular, heating devices, thermal power plants operating on solid fuel. The goal of environmentally sound and efficient use of coal fuel to nominate important issues for research in this area. The solution to the problem of reducing harmful emissions of thermal power plants requires the development of new designs and optimization of operating modes of furnaces, and in General – development of scientific bases of creating ecologically clean thermal power plants for solid fuels. At the same time, physical modeling of real combustion processes or full-scale tests on boilers is characterized by extremely high cost. Consideration of modern thermal and environmental requirements in solving problems of development of perspective and modernization of existing designs of

furnace facilities and optimization of their operating modes requires at present the attraction of numerical simulation methods for the comprehensive study of furnace processes.

However, the formation of complexes (packages) computer programs, sufficiently accurate and versatile to conduct serial numerical experiment on modeling of the totality of the combustion process, remains an urgent task.

Experimental part

As object of research was selected combustion chamber of the boiler BKZ-420, with steam capacity 420 t/h, located at the Almaty CHP-2. The boiler BKZ-420-140-7 designed to work on the Ekibastuz coal for generation of superheated steam in thermal power plants with cogeneration turbines with high

steam parameters. Scheme of the combustion chamber of the boiler and its breakdown into control volumes is shown in figure 1, and the input data used in conducting computational experiments are summarized in table 1.

The combustion chamber of the boiler (figure 2) is equipped with six-vortex flow of the two pulverized coal burners arranged in two levels with three burners on the front wall of the boiler. Extreme burner is turned to the center of the furnace by 8 degrees. The capacity of one burner is 12 t/h of Ekibastuz coal. In the furnace burned dust low-grade high-ash Ekibastuz coal ash content 40%, a volatiles 24%, moisture 5% and the highest calorific value of 16.750 kJ/kg. Fineness of grinding of coal was equal to $R_{90} = 15\%$. All numerical calculations were performed on the above-mentioned technique [1-7].

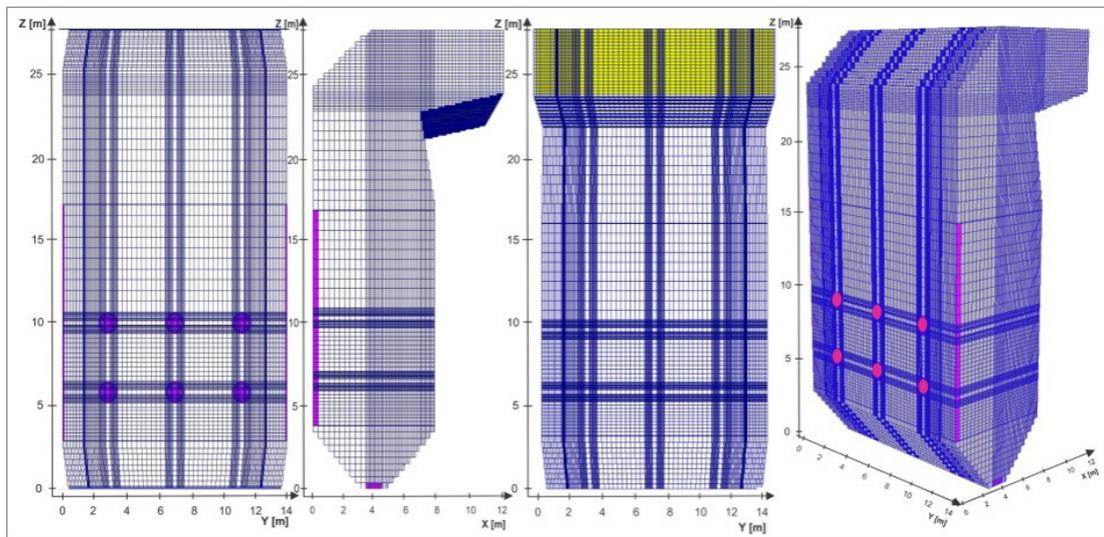


Figure 1 – General view of the combustion chamber of the boiler BKZ-420 Almaty TPP-2 and its breakdown into control volumes

Table 1 – Technical characteristics of the boiler BKZ-420 and input data for numerical simulation

№	Name	Designation	Size	Meaning
	Humidity	W_r	%	5
	Ash	A_r	%	40.0
	The lowest calorific value	Q_r	kcal/kg	4000
	Devolatilization	V_{daf}	%	24-28
	Sulfur	S_t	%	0.4-0.7
The elemental composition of the fuel mass				
	Carbon	C_{daf}	%	82.0
	Hydrogen	H_{daf}	%	5.0

Continuation of Table 1

Nitrogen	N_{daf}	%	1.5
Oxygen	O_{daf}	%	11.5
The number of boilers at thermal power plants	N_B	pieces	7
One of the kindling according to the regulations	t	hour	3.5÷4
Fuel consumption for the boiler (at full load)	B	t/h	72
Type burners		Vortex dual stream	
The number of burners in the boiler	N_B	pieces	6
The performance of one of the burner fuel	B_B	t/h	12
The temperature of Aero mixture after mills	t_a/cm	°C	90÷130
The primary air flow per burner (two separate channels)	V_{PB}	$Nm^3/h * 10^3$	13860 (17879.4 kg/h)
The flow of secondary air to the burner (two channels)	V_{SB}	$Nm^3/h * 10^3$	52140 (67260.6 kg/h)
The temperature of hot air	$T_{H.A.}$	°C	280÷340
The coefficient of excess air for furnace	α_F		1.1÷1.4

Results and discussion

This paper presents results of 3-D modeling of Ekibastuz coal burning in furnace of boiler BKZ-420 Almaty TPP-2 for two variants of the flow of additional air through the holes located on the opposite wall burners and is shown in figure 2.

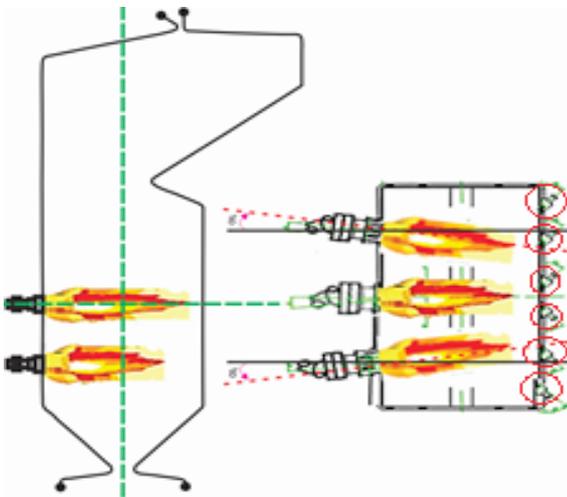


Figure 2 – General view of the industrial boiler BKZ-420 Almaty TPP-2

The burning of fuel at the Almaty TPP -2 is carried out when the value of the mass air flow 5 kg/s through the holes in the wall of the combustion chamber located opposite the burner (see Fig. 2). In the course of research work we have proposed a new mode of operation for CHP-2, when the flow rate

is doubled, and the holes are located at an angle of 45° to the wall of the boiler. The choice of angle of 45° creates the condition for the formation of the arc stream, which protects the walls from overheating and helps to reduce the temperature of the return flow.

As a result of computational experiments on the aerodynamics of the process was constructed of the distribution of the vector full speed, which are shown in figures 3-5.

Figure 3 shows the distribution of the vector of full speed in the longitudinal section ($y=7.18$ m) of the boiler BKZ-420 at a mass flow equal to 5 kg/s (figure 3 a) and 10 kg/s (figure 3 b) and directed from the wall opposite the burners.

Analyzing figure 3, we see that the flows from the lower burners, colliding with the opposite wall, forming a return current. Part of the flow towards the cold region of the funnel forms the bottom of the vortex. Another part is directed upward to the region of the upper burners and openings for secondary air, which also generated turbulence. Maximum values of velocity is in the region of the pulverized coal burner secondary air.

Comparing figures 3 (a) and 3 (b), we note that with increasing mass flow of air from the anti-burners, increases the turbulence as well as maximum, average and minimum speed values. The maximum speed value for the first case is equal to 36.6 m/s, and the second 38 m/s. When the mass flow rate of air is 10 kg/s flow of Aero mixture and air create turbulence above and below the upper burners. The formation of the turbulent eddies creates the best conditions for complete combustion of pulverized coal.

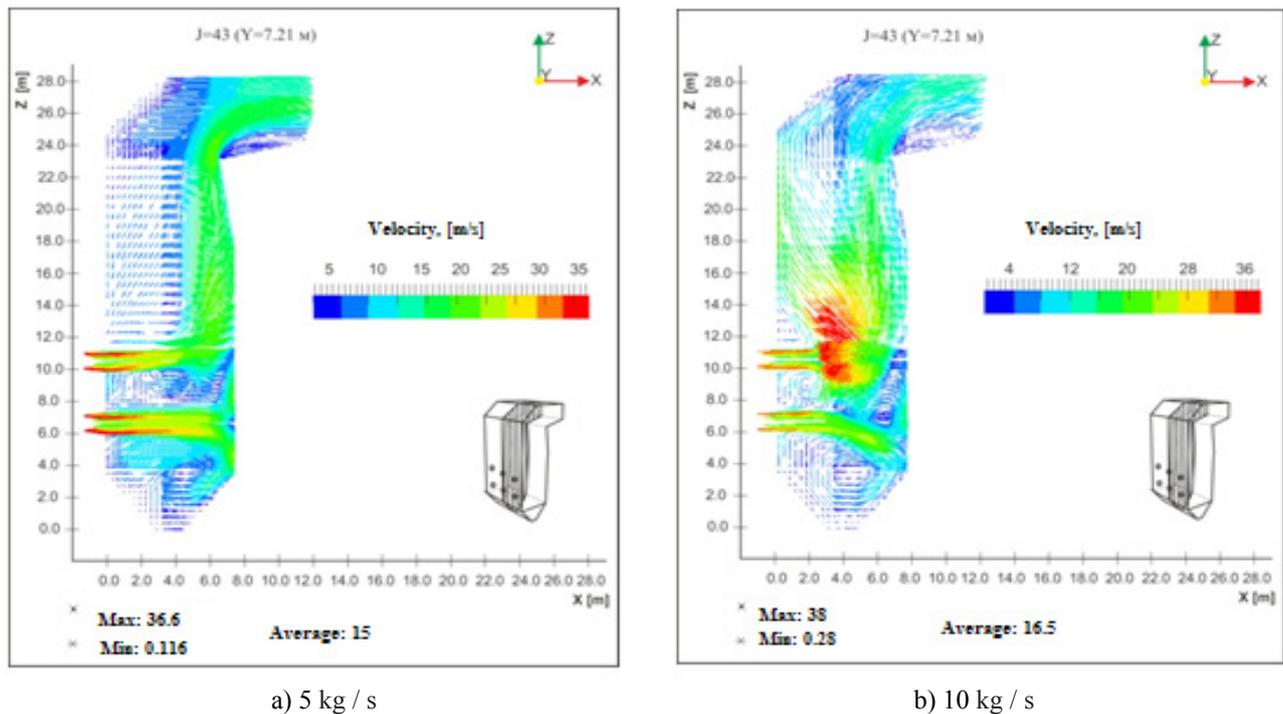


Figure 3 – Distribution of the vector of full speed in the Central longitudinal section ($y=7.18$ m) of the combustion chamber of the boiler BKZ-420 Almaty TPP-2

Figure 4 (a and b) shows the distribution of the vector of full speed in the longitudinal section of the combustion chamber ($X=4$ m), located closer to the burners, for different values of the mass flow of air (5 kg and 10 kg). From the drawings it is seen that in each case at equal speeds of expiry of Aero mixture (coal dust+primary air) from the burner devices, counter flows collide and, due to the presence of the suction cups through the bottom hole in the lower part of the furnace and to form in the area of two longitudinal cold funnel of the vortex.

Formed in this region, the vortices create the conditions for uniform heating of the walls of the combustion chamber and solve the problem of slagging of furnace screens, which prolongs the service life of individual elements of the boiler plant and increases the surface of heat removal.

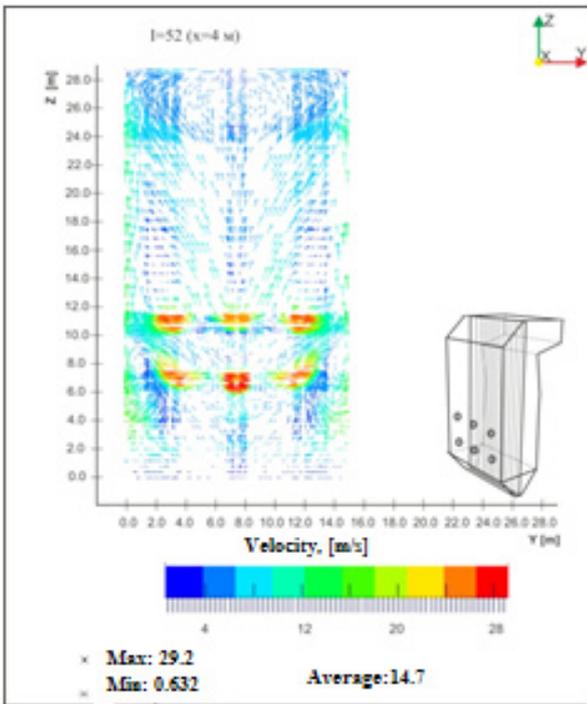
A large swirling flow in the Central region of the combustion chamber is beneficial to the combustion process of pulverized coal due to the turbulent nature of the flow, there is an intensive mixing of the propellant with the oxidant, and thus provides a more complete burnout of coal dust, and this in turn has to use larger fractions of coal particles.

The use of large fractions of the particles of pulverized coal reduces the cost of dust-preparation of coal, transportation and feeding it into the

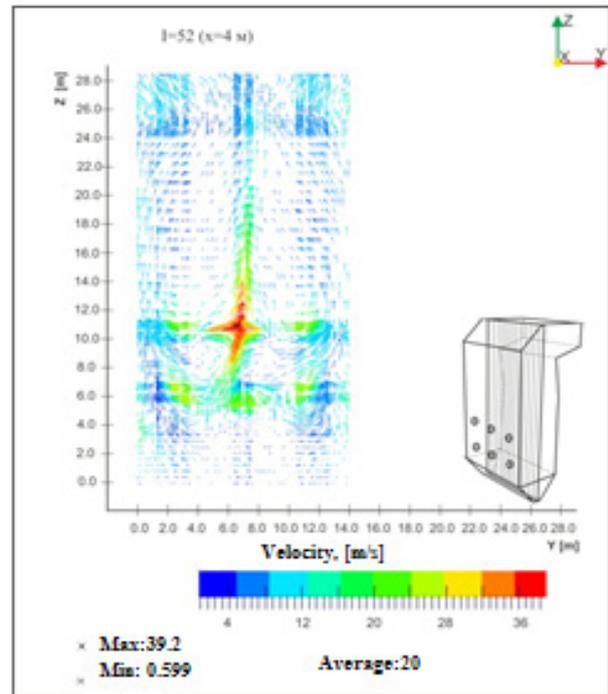
combustion chamber that is more cost-effective. In addition, such an arrangement of furnace processes (figures 3-4) eliminates the need for the installation of devices for the introduction of secondary air to assist combustion of the coal particles, which undoubtedly would have led to an increase in heat losses and increased formation of harmful dust and gas emissions from the combustion chamber into the atmosphere.

5-the figure shows the distribution of the full velocity at 6 m from the burner along the X axis or on the opposite wall from the area burners on 2 m. one Can notice that the velocity values in figure 5 in comparison with its values in figure 4. This is because of the holes on the burners on the opposite wall serves an additional stream of air with high velocity. Figure 5 (b), we see that the maximum speed is 80 m/s. This value 2 times greater than the rate in figure 5 (a).

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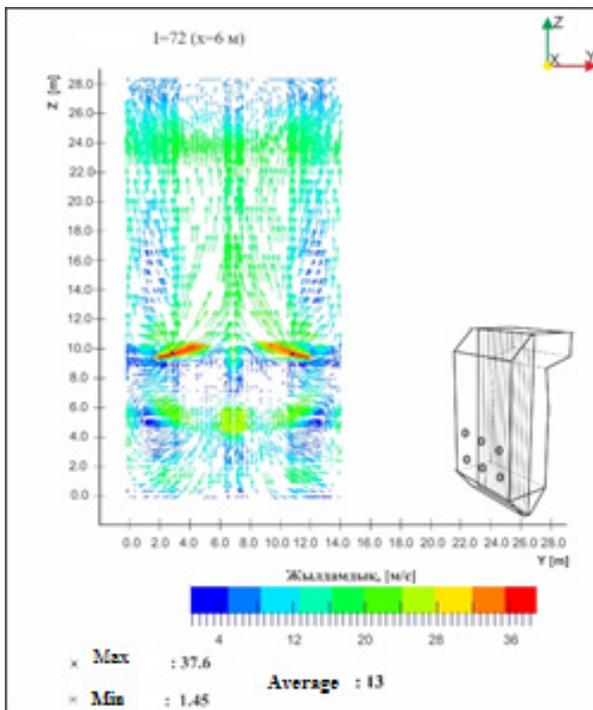


a) 5 kg / s

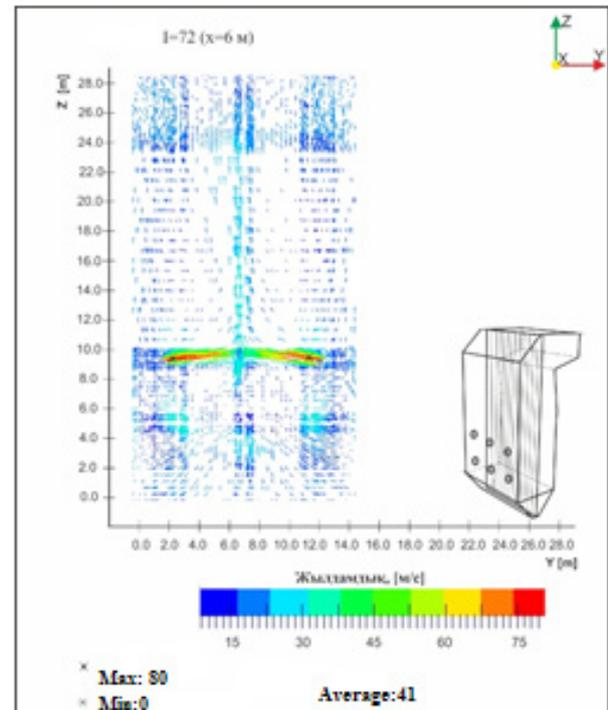


b) 10 kg / s

Figure 4 – Distribution of the vector of full speed in the center of the longitudinal sections of the combustion chamber (X=4 m)



a) 5 kg / s



b) 10 kg / s

Figure 5 – Distribution of the vector full speed in the center of the longitudinal sections of the combustion chamber (X=6 m)

Figure 6 shows a three-dimensional field of temperature distribution in two longitudinal sections ($Y1 = 2.95$ m and $Y3 = 11.4775$ m) of the combustion chamber located in areas of extreme burners of the upper and lower tiers. We see that the flow of additional air, equal to 5 kg/s maximum

temperature is observed at the wall located opposite to the burners and is equal to 1740°C in the lower arusu burner ($Z = 6.82$ m). And at an air flow of 10 kg/s (figure 6b) one can notice that the temperature at the wall has significantly decreased to about 350°C .

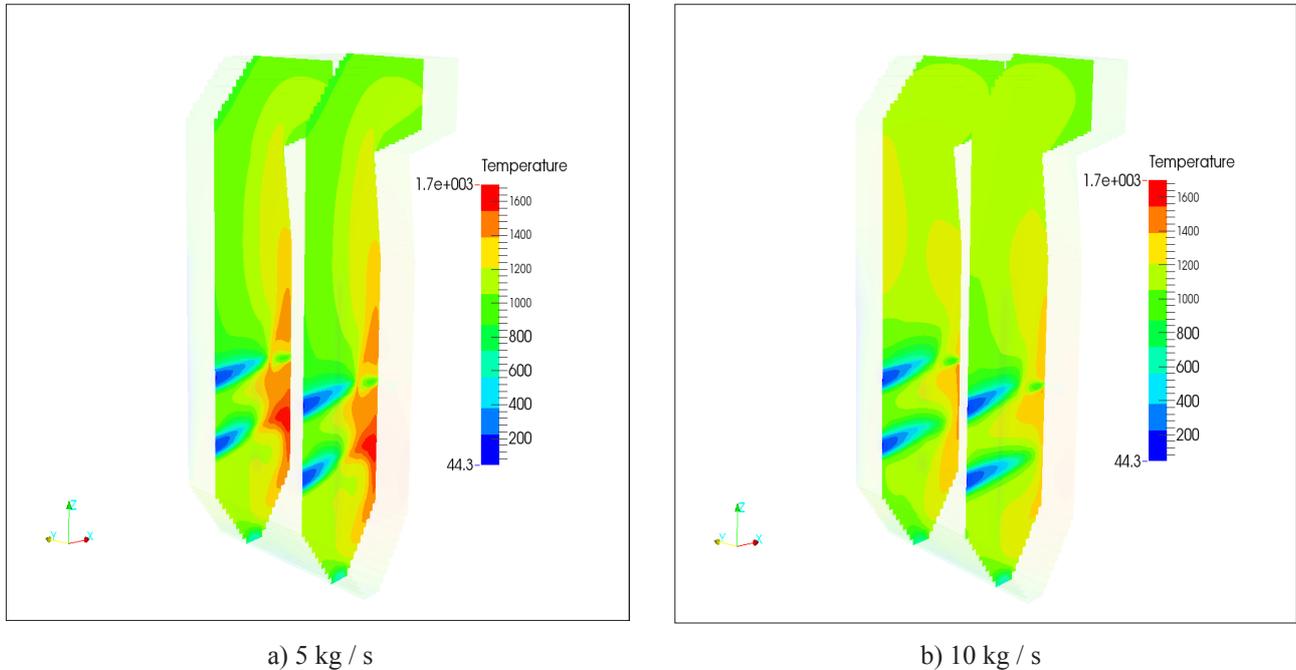


Figure 6 – Three-dimensional distribution of the temperature field in longitudinal cross-section $Y1 = 2.95$ m and $Y3 = 11.4775$ m of the combustion chamber

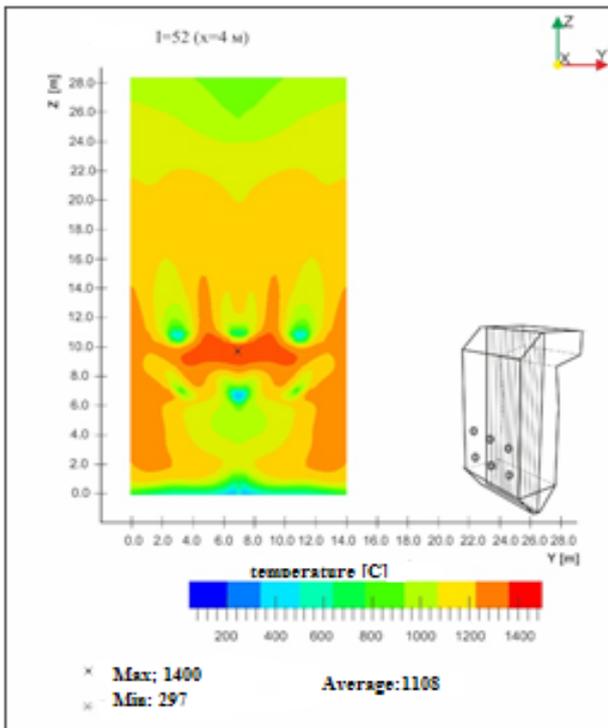
Figure 7 shows the temperature distribution in the longitudinal section along the X-axis ($X = 4.01$ m). From the analysis of figure shows that at low mass flow rate of air (5kg/s) of counter burners torch is formed in a region between the burners (figure 7a), while at higher flow rate (10 kg/s) temperature field (figure 7 b), as it were, in the sky, height of the furnace.

Figure 8 shows the temperature field at the outlet of the combustion space for the two values of the air flow from holes: 5 kg/s and 10 kg/s. As can be seen from the drawings, in the second case (figure 8 b) the area of high temperatures is less than in the first case (figure 8 a).

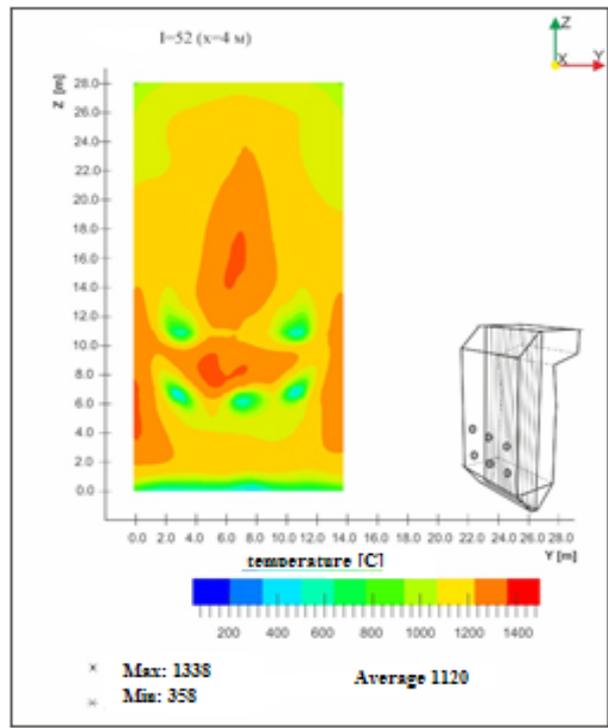
Since the burner and the holes for secondary air is installed on the opposite walls and directed towards each other, in the center of the furnace in the zone of contact flows, as mentioned earlier, the cut. Part of the

flow goes into the area of the cold funnel, forming two longitudinal vortex at a height of below 10.8 m and the part formed by thrust, heading for the exit. Next, as you move to the exit of the furnace and chemical processes weaken (figure 6), the temperature falls and the output of its average value is $\sim 1045^{\circ}\text{C}$ for flow rates of 5 kg/s (figure 6 a) and 987°C – flow rate 10 kg/s (figure 6 b).

The above is confirmed by two-dimensional graphs of the temperature distribution along the height of combustion chamber for two different mass flows of additional air through the opening shown in figure 9. The analysis of the figure shows that at a height of $z_1=6.82$ and $z_2=10.8$ meters burner is pumped through the cold hole, there are minima in the temperature distribution. The output of the camera when the mass air flow 5 kg/s temperature value higher than the supply at 10 kg/s.

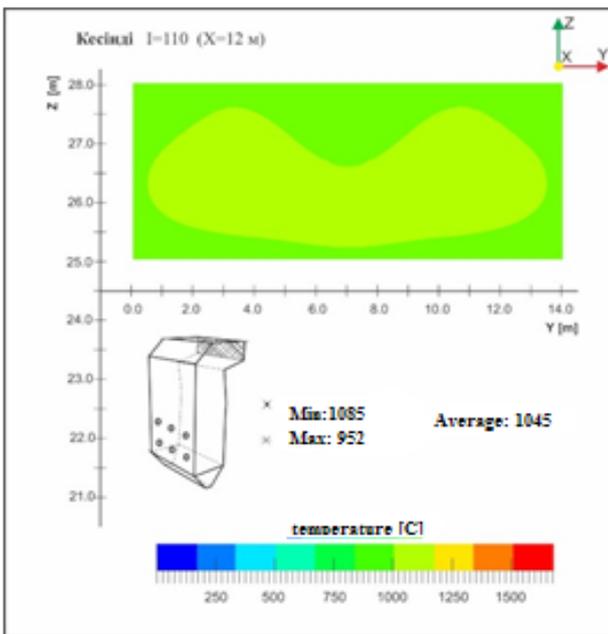


a) 5 kg / s

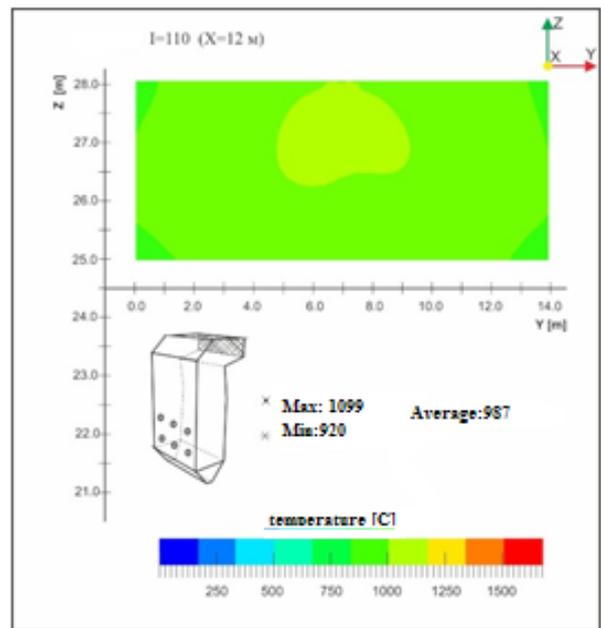


b) 10 kg / s

Figure 7 – Temperature field in longitudinal section of X=4.01 m for different values of mass air flow



a) 5 kg/s



b) 10 kg/s

Figure 8 – Temperature field at the exit of combustion chamber (X=12 m)

This is because in this area are located the burner through which pulverized coal is supplied fuel and oxidizer at a temperature lower than the temperature of the camera. In the region of the belt burners are observed and the maximum temperature, because here is the core of the torch.

The outlet temperature of the furnace is supported by its experimental value ($T=1171\text{ }^{\circ}\text{C}$), obtained directly in the CHP, are given in [8-10] and numerical [11]. Comparing these values, we can conclude: conducted a computational experiment to determine temperature in volume of the combustion chamber, with sufficient accuracy consistent with the measured values of temperature (figure 9). This allows you to judge the reliability of the obtained results and the applicability of physical, mathematical and numerical models to further study the thermal and concentration characteristics of combustion chamber BKZ 420 Almaty TPP-2 [12]. For more references, see [13] – [21].

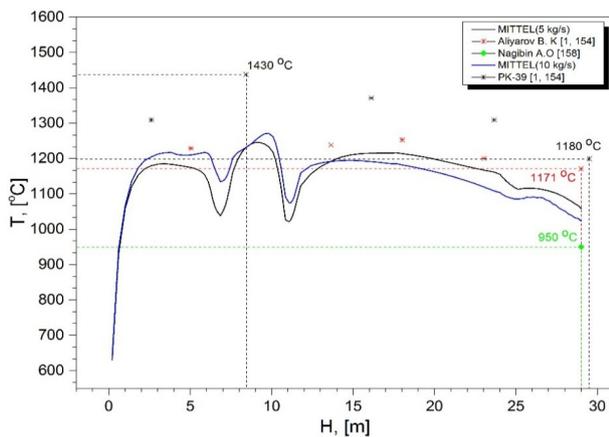


Figure 9 – Average temperature in the height of the boiler furnace

Figure 10 shows the distribution of average values of concentrations of carbon monoxide CO at the height of the furnace for two different values of the mass flow of additional air through the holes located on the opposite burner wall. We see that as a three-dimensional color graph of the temperature field at the exit of the combustion chamber at a mass flow equal to 5 kg/s, the concentration value of carbon monoxide CO higher in comparison with the case where the flow rate is 10kg/s.

Analysis figure 10 shows that the maximum of both curves reach the region of the burners. This is because the largest concentrations coming into this part of the furnace carbon fuel and oxygen oxidizer, the intensity of physic-chemical interaction between

them, causing here a strong increase in temperature and large heat release due to chemical reactions between the propellants and oxidizer.

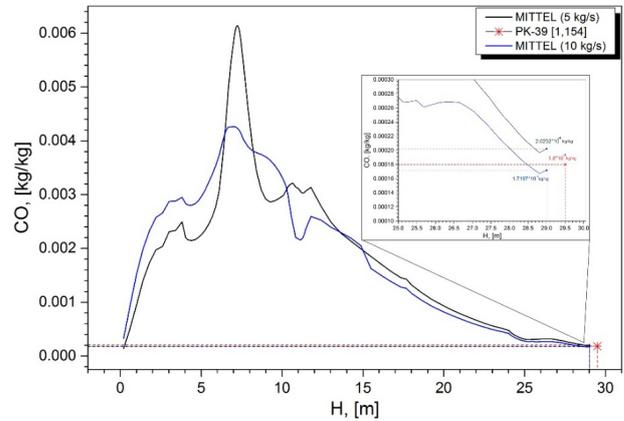


Figure 10 – distribution of the concentration of carbon monoxide CO at the height of the combustion chamber

Figure 11 shows a comparative graph of the distribution of average values of carbon dioxide CO₂ the height of the combustion chamber for the two values of mass air flow 5 kg/s and 10 kg/s.

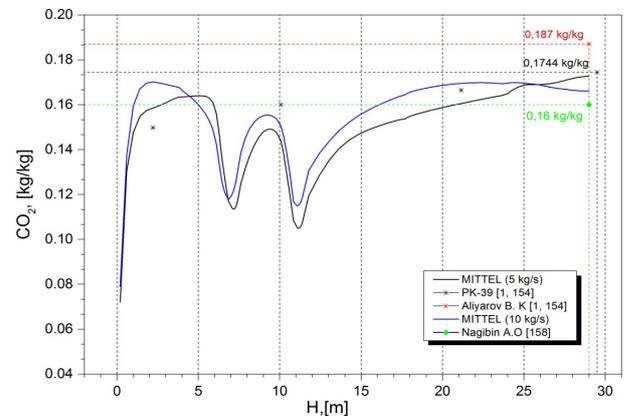


Figure 11 – distribution graph of mean values of carbon dioxide CO₂ the height of the combustion chamber for different values of the mass flow of the additional air

By analyzing this chart you can see that in the location field of burners, and above them, the concentrations of carbon dioxide for the case when the flow of additional air through openings in the wall of the combustion chamber located opposite the burner units equal to 10 kg/s higher than for the air flow 5 kg/s.

Figure 12 shows the comparative distribution of the mean concentrations of NO_2 at the height of the furnace. Analyzing the picture, you will notice that as you move to the exit of the combustion chamber, the concentration of nitrogen dioxide decreases. It is primarily associated with the destruction of nitrogen dioxide NO_2 and its interaction with hydrocarbons, carbon, oxygen, etc., with the decrease of temperature in the upper layers of the gas mixture and of course a decrease in these areas, nitrate concentrations of fuel and oxidant, which is already chemically reacted in the bottom region of the burners.

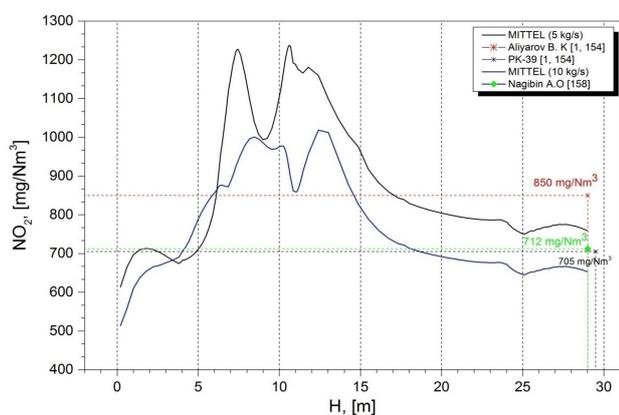


Figure 12 – Graph of the distribution of average values of nitrogen dioxide NO_2 at the height of the furnace for different values of the mass flow of the additional air

Conclusion

By results of researches, we can draw the following conclusions

Computational experiments on the study of aerodynamic, thermal and concentration characteristics in combustion chamber of the boiler BKZ-420 Almaty TPP and the resulting velocity field, temperature, concentrations of harmful dust and gas emissions (CO , CO_2 , NO_2) from the combustion of pulverized coal for different layout options holes and speed boost-extra air (5kg/s and 10 kg/s).

Developed by optimum technology for burning high-ash fuel and energy and the best structural parameters of the combustion chamber of the boiler BKZ-420 Almaty TPP, which allows increasing the wear resistance of power and reducing the emission of harmful substances into the atmosphere. The proposed incineration of Ekibastuz coal lowers the temperature of the walls of the furnace located opposite to the burners at 3000°C , i.e., by 17.24%, and reduces average concentrations of carbon monoxide

at the outlet of the furnace by 15%, carbon dioxide CO_2 by 4.65% and nitrogen dioxide NO_2 by 14% .

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