Research of operation the parameters in the boiler TGMP-204HL at burning gas

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Abstract. The efficiency of fuel combustion in power boilers of thermal power plants largely depends on the layout of the burners in the combustion chamber, on their number and unit capacity. An important condition for the efficiency of the selected combustion mode is the absence of a torch surge from the combustion products onto the screen heating surfaces of the furnace. To prevent the formation of large amounts of harmful emissions of nitrogen oxides into the atmosphere, the necessary requirement for burning fuels is to reduce the local values of the flame temperature in the volume of the furnace. The use of powerful burners in power boilers, with a decrease in their number, leads to an increase in the length of the torch and, with their frontal arrangement, gives a torch thrust onto the rear screen. The article presents the results of an experimental trial of the efficiency of gas burning in the direct-flow supercritical boiler TGMP-204HL of the Surgut GRES-2 PJSC UNIPRO when it is operating on 24 burners at various steam loads. The values of the efficiency of boilers, emissions of nitrogen oxides and the distribution of the radiation intensity of combustion products along the height of the furnace are given. Comparison of the obtained results on efficiency and emissions of nitrogen oxides with the data of the TGMP-204HL boiler using 36 burners is carried out.

Keywords. Boiler, the efficiency factor, natural gas, combustion, burner, intensity, radiation, nitrogen oxide emissions.

1. Introduction

The efficiency of fuel combustion in power boilers of thermal power plants is influenced by many factors, among which the main ones are the design of the burners their location in the furnace, the heat output of the furnace, the temperature and pressure of the feedwater, the method of air heating, the presence of recirculation of flue gases [1-11]. Combustion of fuels in boilers of high power supercritical pressure has its own characteristics as the boilers are once-through. The TGMP-204HL single-shell supercritical boiler selected for experiments with gas combustion is installed at the most powerful in Russia Surgut GRES-2. Boiler TGMP-204HL (station No. 1) is designed to burn fuel using 36 vortex gas-oil burners located in three tiers on the front and rear walls of the furnace. The boiler TGMP-204HL (station No. 1) has been modernized and operates at a load of 800 MW on 24 burners located
on the first lower and second tiers of the Surgut GRES-2. The third upper tier of 12 burners was turned off during the experiments. A feature of the boiler operation to reduce nitrogen oxide emissions is the use of a smoke exhauster for recirculation of combustion products directly into the burners. This article presents the results of an experimental research of the operating parameters of the boiler when using such a scheme for burning natural gas.

2. Literature review
In addition to the design of the TGMP-204HL boiler with a counter-wall arrangement of burners the Taganrog Boiler Plant designed and manufactured for the Ryazan GRES a single-body TGMP-204P boiler with a bottom arrangement of gas-oil direct-flow vortex burners of the Ural ORGRES design [12]. The purpose of the development of the TGMP-204P boiler is to reduce the uneven distribution of heat generation along the height of the furnace, which has a TGMP-204HL boiler with a counter wall arrangement of 36 burners [13, 14]. When the bottom is located in the boiler TGMP-204P, the consumption of natural gas through one burner is $16.8 \times 10^3$ m$^3$/h, and their number is 12 pieces (Figure 1).

![Figure 1. The diagram of the bottom arrangement of burners in the TGMP-204P boiler.](image)

Structurally the bottom burner has a central supply of combustion gas 1 from the collector to the coaxial conical pipe 13 (Figure 2). Typical tangential peripheral vane air swirlers 3.5 with fixed blades have a twist parameter of about unity. To improve mixture formation during fuel oil combustion, an axial air swirler 6 is provided in the bottom burner design.

A characteristic feature of the hearth arrangement is the low radiation values in the lower part of the furnace volume (Figure 3). According to the results of tests of TGMP-204P boilers at the Ryazan GRES, the intensity of flame radiation in the lower part of the furnace decreased by 20% compared to the TGMP-204HL boiler. As a result, the temperature of the metal of the shield tubes of the lower radiation part decreased by 40 °C, which made it possible to increase their service life. However, the use of the hearth layout resulted in a decrease in the efficiency of the TGMP-204P boiler, compared to the TGMP-204HL boiler, due to the increased temperature of the exhaust gases [12-13].

To reduce the temperature of the exhaust gases and increase efficiency, the TGMP-204HL boiler (station No. 1) at Surgut GRES-2 was upgraded by increasing the flow capacity of the burners for the burned gas and increasing the air twist. This made it possible to reduce the number of working burners from 36 to 24 and reduce the temperature of the exhaust gases by disabling the third upper tier of 12 burners.

3. Materials and Methods
The single-flow single-body boiler TGMP-204HL (marking according to GOST PP - 2650-25-545 / 542GM) produced by the Taganrog boiler plant is designed to produce supercritical steam with a pressure of 25.5 MPa and a temperature of 545 °C when burning natural gas and working in a block with a single-shaft condensing turbine LM3 K-800-240-5. The TGMP-204HL boiler with a gas-tight steam capacity of 2650 t/h has a U-shaped layout. The boiler consists of a combustion chamber and a downcomer flue, connected in the upper part by a horizontal rotary flue. The boiler is equipped with two freestanding regenerative rotating air heaters SKHP 32/1850 with a rotor diameter of 14 m.
Figure 2. The diagram of the bottom burner of the TGMP-204P boiler at Ryazan GRES with a twist parameter of 1.061: 1 – central natural gas supply; 2 – air supply to the central annular channel, 3 – air-swirling tangential blades of the central register, 4 – air supply to the peripheral annular channel, 5 – air-swirling tangential blades of the peripheral register, 6 – axial air swirler for burning fuel oil; 7 – recirculation flue gas supply, 8 – compensatory lenses, 9 – embrasure, 10 – electric igniter, 11 – oil nozzle, 12 – pneumatic valve, 13 – coaxial conical pipe.

Figure 3. The intensity of the flame radiation $q_f$ along the height $h$ of the middle section of the furnace of the TGMP-204P boiler at Ryazan GRES with a bottom arrangement of 12 burners and for the TGMP-204HL boiler of the Surgut GRES-2 with a wall opposite arrangement of 36 burners on three tiers during gas combustion with a recirculation coefficient of the unit equal to 23% and electrical loads 800 MW [12-14].
The air heating temperature is 360 °C. The design feed water heating temperature is 270 °C at a pressure of 31 MPa. The boiler combustion chamber is made in the form of a rectangular cross-section with a depth of 10.3 m and a width of 20.7 m, shielded by a bottom screen, lower, middle and upper radiation parts in the form of panels of floating pipes. The boiler does not have its own frame and is suspended from the metal structures of the boiler house. The mark at the top of the boiler is 67.3 m.

The bottom screen is located in the lower part of the firebox and constructively shields a part of the front and rear walls up to the level of 22.8 m. In addition, two middle panels of the first lower radiation part (LRP-1) are located on the side walls of the furnace up to a mark of 22.8 m. The second lower radiation part (LRP-2) is formed from eight extreme panels of the front and rear walls of the lower part of the furnace (along two panels on the side of the side walls) located up to 22.8 m mark and the four outer panels of the side walls to the 22.8 m mark.

The first medium radiation unit (MRP-1) is a direct continuation of the LRP-2 screens. The second middle radiation part of the MRP-2 screens the central part of the front, rear and side walls of the furnace and is located between the marks of 22.8 m and 35.8 m. The upper radiation part (URP) shields the upper part of the combustion chamber and occupies completely the front, side and rear furnace walls between 35.8 m and 55.3 m marks, and the URP of the rear wall of the furnace screens the aerodynamic protrusion and part of the horizontal flue at the 43.6 m mark. The ceiling of the horizontal flue and convection shaft furnace is screened by a ceiling screen. On the side walls of the reversing chamber between the marks of 43.6 m and 55.3 m, there are screens of the horizontal flue. In the horizontal gas duct in the area of the gas window, a platen superheater (PSH) is installed then the first and second stages of the convective high-pressure superheater CHPSH-1, 2 and the second stage of the convective low-pressure superheater CLPSH-2 are installed along the gas flow. Gases in the convection shaft are installed CLPSH-1 surfaces. The last in the flow of gases are the blocks of the water economizer. The rear screen of the URP forms an aerodynamic protrusion in the upper part of the combustion chamber which protects the screens from direct radiation from the combustion chamber.

The steam-water path of the boiler is done double-flow with autonomous regulation of the medium flow and temperature of the superheated steam. The primary steam temperature is controlled by injections in front of the screens and in the cut of the high-pressure superheater. To regulate the temperature of the secondary steam, two recirculation smoke exhausters GD-26-12-1 are installed which collect the flue gases behind the convection shaft and supply them to the burners. Injections after the first stage of the low pressure superheater are also used. The recirculation gases are injected into the burners and also serve to reduce the rate of high-temperature corrosion of the LRP and suppress nitrogen oxides. In the design, the combustion chamber is equipped with 36 gas-oil burners with a capacity of 60 MW, placed in opposite directions, 18 pieces each on the front and rear walls of the furnace in three at elevations of 12.9 m, 15.9 m and 18.9 m. Air and recirculation gases are supplied to the burners by common ducts. The boiler is designed to operate on a balanced draft and is equipped with two VDN-36 x 29 blower fans and two DOD-43-500 smoke exhausters GM.

In figure 4 shows a diagram of the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 when using 24 burners during the experiments during gas combustion. The measurement of the light emission from the flame was carried out through 44 hatches, on the walls along the height of the firebox from service areas 3 (Figure 4). In figure 4 shows, as an example, the design arrangement of 36 burners in three tiers (view A). As already noted, the experiments were carried out with 6 burners on the front wall and 6 burners on the back wall turned off on the third tier.

The use of 24 burners for use on three tiers is need, due to the fact that the temperature of the combustion products at the outlet of the furnace when using the third upper tier increases greatly and the heat load on the superheating surfaces increases. This leads to the need to turn on desuperheaters so that the temperature of the superheated steam does not exceed 545 °C. When the burners of the third tier are switched on, the temperature of formation of thermal nitrogen oxides also increases, since the temperature of the combustion products recirculated to the burners from the downcomer flue also increases.

The diagram of the vortex gas-oil burner with a thermal power of 60 MW used on the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 is shown in figure 5.
**Figure 4.** Diagram of the longitudinal section of the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 using 24 burners at the nominal capacity when burning gas: 1 – burners, 2 – evaporating surfaces, 3 – service platforms, 4 – superheating surfaces, 5 – intermediate superheater, 6 – economizer, 7 – gas recirculation, 8 – regenerative air heater, 9 – heated air, 10 – superheated supercritical steam, 11 – steam for reheat, 12 – steam after reheat, 13 – feed water.

**Figure 5.** The diagram of the oil-gas burner used on the TGMP-204HL boiler (station No. 1) of Surgut GRES-2 with a capacity of 5.2 t / h for fuel oil or 5.6 x 103 m³ / h for natural gas with a twist parameter of 1.115: 1 – central supply natural gas; 2 – air supply to the central annular channel, 3 – air-swirling tangential blades of the central register, 4 – air supply to the peripheral annular channel, 5 – air-swirling tangential blades of the peripheral register, 6 – air pressure sensors; 7 – recirculation flue gas supply, 8 – compensatory lenses, 9 – embrasure, 10 – electric igniter, 11 – oil nozzle, 12 – pneumatic valve.
Tangential blades of air swirling registers 3.5 (Figure 5) are non-rotating. Different amount of thermal expansion of the air box with built-in burners and screens of the combustion chamber is eliminated by lens compensators 8. The pneumatic valve 12 prevents the knocking out of combustion products into the boiler room.

The measurement of the radiation intensity of the torch was carried out with a TERA-50 total radiation radiometer with a RK-15 graduation. The temperature of combustion products in the near-wall layer of the furnace was measured using double chromel-alumel thermocouples [2]. The concentration of nitrogen oxides NOx in the combustion products in the operating section was measured with a DAG-500 gas analyzer. The error in determining the efficiency was ± 0.71%. The operating and balance parameters of the boiler operation were measured using standard instruments with checking their readings by the sensors of the primary calibrated instruments of the set-up and testing group of the Surgut GRES-2. The heat of combustion of the fuel gas was determined in the central laboratory of the Surgut RES-2 by measurements on an ABK-1V electronic bomb calorimeter. The Urengoy natural gas with a combustion heat $Q^\text{np} = 33662 \text{ kJ} / \text{Nm}^3$ was burned.

4. Results

Table 1 shows the results of a study of the operating modes of the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 during gas combustion in 24 burners with the third upper tier turned off, on which, according to the design data, 12 more burners should operate. Of these, 6 burners are installed on the front wall and 6 burners - on the rear wall of the furnace.

| Parameter                                      | Electrical load of the unit, MW |
|------------------------------------------------|--------------------------------|
| Steam capacity, t/h                           | 440                                           |
|                                               | 550                                           |
|                                               | 650                                           |
|                                               | 750                                           |
|                                               | 810                                           |
| Superheated steam pressure, MPa               | 23.5                                          |
|                                               | 23.5                                          |
|                                               | 23.5                                          |
|                                               | 23.5                                          |
|                                               | 23.5                                          |
| Superheated steam temperature, °C             | 545                                           |
|                                               | 545                                           |
|                                               | 545                                           |
|                                               | 545                                           |
|                                               | 545                                           |
| Intermediate superheat steam temperature, °C | 525                                           |
|                                               | 527                                           |
|                                               | 529                                           |
|                                               | 530                                           |
|                                               | 531                                           |
| Feed water temperature, °C                    | 240                                           |
|                                               | 250                                           |
|                                               | 260                                           |
|                                               | 268                                           |
|                                               | 272                                           |
| Combustion gas consumption, thousand nm3/h    | 127                                           |
|                                               | 154                                           |
|                                               | 184                                           |
|                                               | 214                                           |
|                                               | 236                                           |
| Gas pressure before burners, MPa              | 0.035                                         |
|                                               | 0.048                                         |
|                                               | 0.065                                         |
|                                               | 0.083                                         |
|                                               | 0.093                                         |
| Exhaust gas temperature, °C                   | 127                                           |
|                                               | 130                                           |
|                                               | 135                                           |
|                                               | 142                                           |
|                                               | 145                                           |
| Heat loss with flue gases,%                   | 5.68                                          |
|                                               | 5.81                                          |
|                                               | 6.02                                          |
|                                               | 6.34                                          |
|                                               | 6.38                                          |
| Recirculation ratio,%                         | 52                                            |
|                                               | 45                                            |
|                                               | 34                                            |
|                                               | 30                                            |
|                                               | 1,024                                         |
| Excess air ratio in the operating section     | 1.041                                         |
|                                               | 1.035                                         |
|                                               | 1.029                                         |
|                                               | 1.026                                         |
|                                               | 287                                           |
| The content of nitrogen oxides NOx in combus-
| tion products, reduced to $\alpha = 1.4, \text{mg} / \text{Nm}^3$ | 80                                           |
|                                               | 90                                            |
|                                               | 148                                           |
|                                               | 196                                           |
|                                               | 287                                           |
| Gross boiler efficiency,%                     | 93.95                                         |
|                                               | 93.83                                         |
|                                               | 93.75                                         |
|                                               | 93.50                                         |
|                                               | 93.37                                         |

On the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2, using 24 burners instead of 36 burners, the flame radiation intensity $q_f$ increases at altitudes $h_t$ in the range from 10 to 20 m (Figure 6).
In comparison with the data in figure 3 for the bottom arrangement of the burners of the TGMP-204P boiler and the wall-mounted opposite arrangement of 36 burners in three tiers on the TGMP-204HL boiler, with an electric load of the 810 MW unit in the TGMP-204HL boiler with 24 burners located in two tiers, the radiation intensity $q_f$ in the altitude area from 10 to 20 m much higher. In this case, the recirculation coefficient was 26 %, which led to a decrease in the flame temperature at the burner level. For the data in figure 3, the recirculation ratio is 23%.

5. Discussions
Combustion of gas in the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 with 24 burners with an increased twist parameter and a recirculation coefficient made it possible to reduce the concentration of nitrogen oxides in comparison with the TGMP-204HL boiler [14] operating on 36 burners (Figure 7).

**Figure 6.** The intensity of the flame radiation $q_f$ along the height $h_f$ of the middle section of the furnace of the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 with a wall-mounted counter-arrangement of 24 burners on two tiers during gas combustion for electrical loads of the 440, 550, 650 and 810 MW unit.

**Figure 7.** The concentration of nitrogen oxides $\text{NO}_x$ in combustion products, reduced to the excess air ratio $\alpha = 1.4$, when burning gas in the TGMP-204HL boiler (station No. 1) of the Surgut GRES-2 with 24 burners with an increased twist parameter depending on the electrical load $N$ block in comparison with the data [14] for TGMP-204HL with 36 burners located in three tiers.
Combustion of gas in a TGMP-204HL boiler in 24 burners located in two tiers allows obtaining higher efficiency values as compared to combustion in 36 burners located in three tiers [14] (Figure 7). This is due to the fact that when 36 burners are used and the third tier is used, the temperature of the combustion products at the outlet from the furnace increases and at the same time, heat losses with exhaust gases increase due to an increase in their temperature in the balance section.

To further increase the efficiency of gas combustion in TGMP-204HL boilers with 24 burners located in two tiers it is necessary to replace tangential vane air swirlers with axial peripheral ones, which make it possible to obtain higher values of the swirl parameter [10, 17]. In this case, it is also necessary to replace the central cone-shaped gas supply with a combined one, which includes peripheral gas distribution pipes with rotary nozzles and a coaxial central nozzle, which will improve mixture formation in the flame and reduce the intensity of the flame radiation at the burner level.

6. Conclusions
1. Modernization of the TGMP-204HL boiler for gas combustion in 24 burners located in two tiers, in comparison with combustion in 36 burners located in three tiers with an increase in the air swirl parameter in the burners allows to obtain an increase in efficiency and a decrease in the concentration of nitrogen oxides in the outgoing gases.

2. To further increase the efficiency of gas combustion in the TGMP-204HL boiler in 24 burners located in two tiers it is necessary to replace tangential air swirlers in the burners with axial peripheral ones and use combined gas distribution using peripheral gas supply pipes with nozzles and a central coaxial-conical gas supply which will reduce the local values of the flame radiation intensity at the level of the burners.

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