Implementation of a Low-NOx Firing System to Burn Coals from the Kansko-Achinsk Coal Basin on Boiler P-59 of a 330 MW Power Unit

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The paper presents the key results of refurbishment of boiler P-59, unit No.2, at the Ryazanskaya power plant of PAO OGK-2 aimed at switching the boiler to firing off-design Kansko-Achinsk coals, increasing its capacity and reducing NOx emissions. The paper also presents the data related to main technical, economic and environmental performance of the boiler. It estimates the efficiency of the applied methods of design and implementation of a low-NOx firing system for solid fuel.

Keywords: low-NOx firing system, nitrogen oxides, NOx, Kansko-Achinsk coal basin, boiler P-59, CFD-simulation.

INTRODUCTION

A topical issue in design of firing systems for large-scale coal-fired boilers is the implementation of technical solutions based on the present-day scientific and technical achievements, ensuring the best possible combinations of reliability, efficiency and environmental safety criteria.

Today, one of the efficient ways to reduce nitrogen oxides (NOx) when firing solid fuel in a boiler furnace is to arrange low-NOx staged flame combustion [1]. OOO ZiO-COTES focuses on the solution of such tasks.

Refurbishment of boiler P-59 (Pp-990-25-545/545 BT), unit No.2, at the Ryazanskaya power plant of PAO OGK-2 is one of the joint projects for the implementation of low-NOx solid fuel combustion, performed together with AO Machine Building Factory of Podolsk.

BOILER UNIT DESCRIPTION

Low-grade brown coal from the Moscow area (Q_i^r=2530 kcal/kg, A^r=22.4 %, W^r=34 %) was used as a design as-received fuel. The boiler uses a direct-firing coal pulverizing system with hammer mills and dry bottom ash removal.

Moscow area coal met its design parameters during the first years of operation. Later, its calorific value decreased, and ash content increased. Firing of a high-ash low-quality coal for a long period of time resulted in a severe wear of the boiler flue gas ducts, IDF blades, increased inflows to the furnace and convective passes, which resulted in draft limits.

In 1990, 300 MW power units of the first stage of the plant were derated to 280 MW power units for the reason of a lower quality fuel as compared with the design one.

Due to fuel policy changes at the Ryazanskaya power plant, since 1992, the plant has begun to fire the coals from the Kansko-Achinsk basin (Table 1). However, the operation of the boilers firing the coals from the Kansko-Achinsk basin revealed a number of problems when the loads of the power units exceeded 260 MW.

Figure 1 shows a longitudinal section view of boiler P-59.

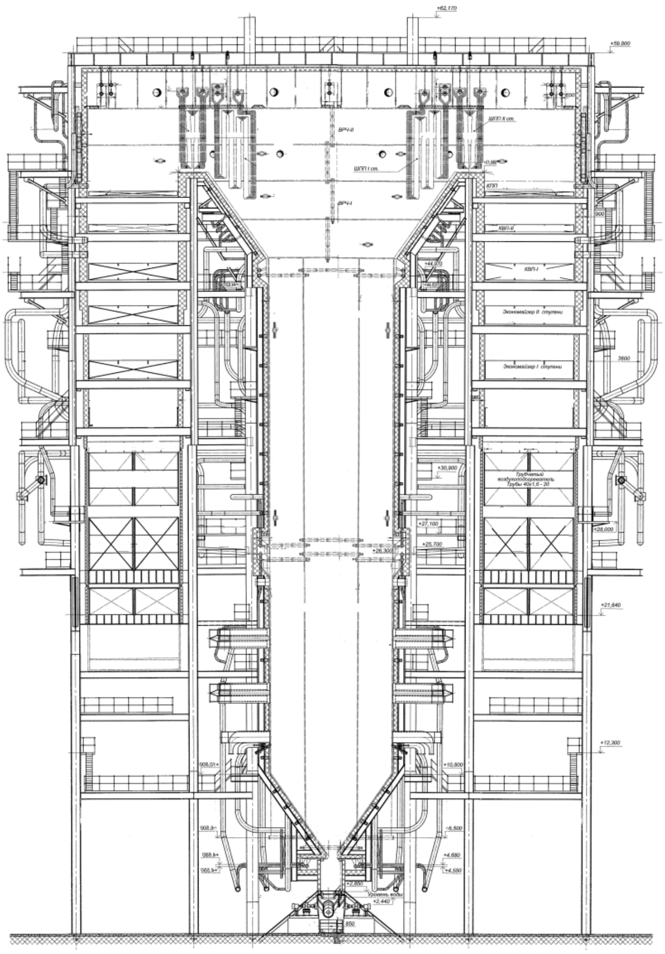

Figure 1 - Longitudinal section view of boiler P-59

Table 1 - Characteristics of coals fired in boiler P-59 in the Ryazanskaya power plant

Description	Symbol	Deposit		
		Moscow	Pereyaslov	Berezovo
Lower heating value (as-received), kcal/kg kJ/kg	Q_i^r	2530 10586	4400 18410	3740 15659
Hygroscopic water, %	W_h	7-8	9-12	12-16
Volatiles: dry ash-free, %	V^{daf}	47	46.6	45.7
Water content, %	W^r	34	28.6	34.8
Ash, %	A^r	22.4	5.1	3.7

These problems were particularly aggravated when the Ryazanskaya power plant received large quantities of Berezovsky coal early in 2000. The combustion of this coal with minimal admixtures of coal from the Moscow area on P-59 boilers resulted in the increased slagging of the convective heating surfaces of the boilers and forced reduction in the load of the units down to 200 MW with continuous operation during 2-4 weeks. In order to increase slag-free load of its units in 2000-2001, the Ryazanskaya power plant together with ORGRES determined the structure of the operational mix consisting of Berezovsky and Moscow region coals (70-80% of Berezovsky and 20-30% of Moscow coals) close to the optimal structure at which they managed to increase the slag-free load of the units up to 250-260 MW.

To increase slag-free capacity of the boilers operating on the Kansko-Achinsk coals, in 2001, the management of the Ryazanskaya power plant decided to retrofit the furnace of boiler No.2 using the design prepared by Politechenergo (St. Petersburg) making use of low-NOx swirl technology of coal combustion. Retrofit scope included the following:

– burner downward angle: 20° for the upper level and 30° for the lower level;

– retrofit of mill separators to ensure coarser dust crushing;

– installation of dedicated deflection-nozzles for bottom air supply;

– disconnection of every second pulverized coal pipe of the upper level using plugs with the flow rate increased up to 36 m/s.

The retrofit carried out using low-temperature swirl system allowed increasing the unit load up to 260-280 MW and improving the environmental performance of the boiler; however, there were some limitations associated with abrasive wear of sloping bottom tubes and PC lines.

Because of all the problems and limitations coming up, the retrofit activities went on aimed at reaching the capacity of the power unit up to 330 MW.

BOILER REFURBISHMENT

Within 2011-2016, a low-NOx system for firing solid fuel for boiler P-59 No.2 was successfully designed, engineered and implemented.

While looking for proper technical solutions, an important aspect was a computational simulation of combustion processes within the boiler furnace chamber using ANSYS FLUENT software for 100%, 70% and 50% loads with different combination of operating mills when firing Pereyaslovsky coal from the Kansko-Achinsk basin.

CFD-simulation made it possible to determine velocity and temperature fields throughout the entire furnace chamber volume, concentration of chemicals and nitrogen oxides, discrete phase concentration, fuel burnout (unburned carbon), as well as the trends in changes of average temperatures and concentration of gases in the cross-sections and along the furnace height (Figures 2, 3) [6].

Computational simulation of combustion processes within the furnace chamber of boiler P-59 confirmed that all the necessary conditions for a reliable and costefficient boiler operation with minimum nitrogen oxides (NOx) emissions at various loads and with different combination of operating mechanisms were ensured in full.

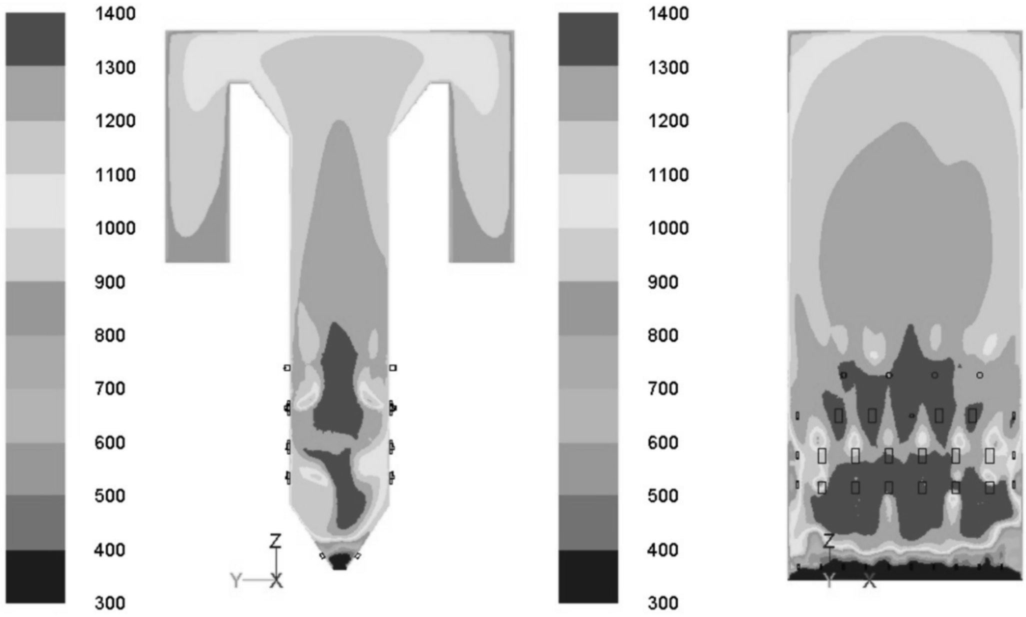

Figure 2 - Temperature field in the axial sections at nominal boiler load, °C

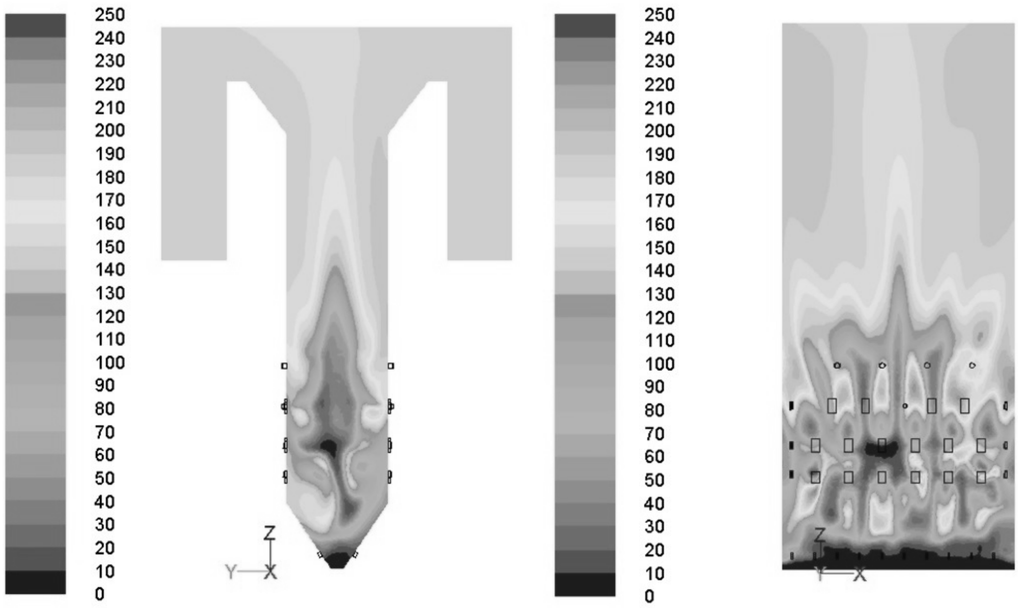

Figure 3 - Nitrogen oxides concentration field in the axial sections at nominal boiler load, ppm

Based on the results of the CFD-simulation, the following technical solutions have been approved:

– Arrangement of vertically staged combustion with a part of secondary air fed via OFA ports and bottom air supply nozzles. Bottom air supply also enables after-burning of fuel that falls into the sloping bottom, protection of its slopes and more efficient usage of heating surfaces of the sloping bottom along its full height;

– Input of recirculation gas in the furnace chamber through the application of gas fuel drying, which reduces flame temperature and evens the temperature fields;

– Arrangement of horizontally staged combustion through maintaining secondary air supply to non-operation burners in the same amount as to the operating burners;

– Supply of dust-air mixture and secondary air distributed along the furnace chamber height, which elongates combustion zone and reduces flame temperature;

– Larger number of levels - 3 instead of 2 - enables reduced heat release rate in the burner levels ensuring allowable (regulatory) values and creates favourable conditions for lower heating surfaces slagging. Moreover, increased fuel proportion for the first two levels ensures excess air at the outlet of each level, which is important in terms of lower nitrogen oxides (NOx) emissions;

– Arrangement of curtain air supply reduces the temperature of gas near the furnace front and rear waterwalls, thus protecting the walls against slagging and high temperature corrosion in the reducing environment;

– Increased by 50% surface of a primary platen superheater to reduce gas temperature upstream of a convection superheater.

REFURBISHMENT RESULTS

The final stage of No.2 boiler P-59 refurbishment for the Ryazanskaya power plant, branch of PAO OGK-2, included performance adjustment. The purpose of operational tests was to experimentally determine the effectiveness of the technical solutions applied for upgrading of the boiler firing system.

Based on the results of the performance adjustment, the main values in terms of boiler technical, economic and environmental performance were identified. Table 2 shows the characteristics received experimentally by the engineers from ZiO-COTES during the tests carried out before the refurbishment of the boiler unit and after arranging staged low-NOx system of flame combustion, as well as design values under the retrofit project.

Table 2 – Technical, economic and environmental parameters of the boiler

Description	Experimental data			Design values under the refurbishment project
	Before refurbishment	After refurbishment	After adjustment	
Power unit rated load, MW	270	330	330	330
Rated live steam mass flow, t/h	890	990	990	990
Live/reheat steam temperature downstream of the boiler, °C	545 / 545	545 / 545	545 / 545	545 / 545
Live/reheat steam pressure downstream of the boiler, kgf/cm^2	255 / 39	255 / 39	255 / 39	255 / 39
Inflows to the boiler gas duct, %	68.0	70.3	25.0	25.0
Flue gas temperature, °C	186	180	164	164
Flue gas waste heat loss, q_2, %	13.49	11.95	8.03	8.03
Unburned combustibles loss, q_3, %	0.2	0	0	0
Unburned carbon loss, q_4, %	1.14	1.43	1.43	1.65
Loss due to external cooling, q_5, %	0.42	0.19	0.19	0.25
Loss due to bottom ash temperature, q_6, %	0.09	0.01	0.01	0.01
Gross boiler efficiency, η^{gr}, %	84.66	86.42	90.34	90.06
NOx concentration under normal conditions and O_2=6%, mg/Nm^3	380	385	370	370

Operation of coal pulverizing units is the major factor having a negative impact on the boiler main technical, economic and environmental parameters. Before the adjustment, pulverized coal downstream of the mill was of an unsatisfactory quality:

increased water content (exceeding the design value by more than 1.5…2 times); presence of coarse fraction R_{1000}=6…8% with a relatively low general milling fineness R_{90}=40%, which is caused by pulverized coal slippage through the separator due to incomplete implementation of all design solutions.

It should be noted that the value of heat loss with flue gas slightly exceeds the design values. First of all, it is due to high temperature of flue gases, which is affected by a number factors, such as the following:

- Increased hot air flows from the air duct to the gas duct up to the 3rd stage of the tubular air heater I and, as a result, its inadequate performance;
- High temperature of cold air upstream of the air heater;
- Excessive inflows to the boiler gas duct.

To improve boiler economic performance and operating efficiency, the measures for adjustment of coal pulverizing equipment and sealing of the gas duct need to be taken.

CONCLUSIONS

Despite the revealed drawbacks related to incomplete implementation of design solutions and installation imperfections, in general, the refurbishment conducted can be deemed successful. The boiler reliably operates at the rated load of 330 MW.

Design capacity and steam parameters of the boiler are ensured within the entire operating load range (0.55…1.0 D_{nom}).

Boiler furnace conditions ensure stable ignition and burnout of pereyaslovsky coal with no evident slagging of furnace waterwalls and convection heating surfaces throughout the entire load range.

Furnace exit gas temperature amounts to 950…1000°C, which, based on the experience of firing similar composition fuels in boilers, ensures slag-free operation of heating surfaces in the convection pass.

NOx content downstream of ID fans is at the level of 370…385 mg/Nm^3 with 7, 8 mills in operation @ O_2=3.5% at the reference section under the boiler rated load.

Also, the new methods (CFD-simulation) of design of low-NOx solid fuel firing systems made it possible to most clearly state the required technical solutions ensuring cost-effective boiler operation and low NOx emissions.

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