EXPERIENCE IN CONVERTING TPP-210A BOILERS WITH 300 MW POWER UNITS TO BURNING GAS COAL AT THE TRIPILLYA THERMAL POWER PLANT

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This article presents key technical solutions for converting two TPP-210A boilers with 300 MW power units to burning gas coal at the Tripillya thermal power plant with the maximum use of existing equipment. It describes difficulties that were overcome during the reconstruction and commissioning of the boilers, as well as the operational characteristics of the boilers after the reconstruction. The technical solutions developed enable implementation of the transition from gas coal to lean coal and vice versa in the boiler of power unit No. 3 without changing the equipment composition, but using only the operating parameters of coal pulverization and combustion.

Keywords: pulverized coal boiler; pulverized-coal system; high-concentration fuel dust supply; swirl burners; anthracite; lean coal; gas coal.

Ukraine is in the top decile of coal mining countries in the world in terms of black coal reserves and is in the top three in terms of anthracite reserves. Therefore, coal-fired power plants are considered as the basis of the country's energy security. Until 2014, pulverized-coal thermal power plants (TPPs) accounted for almost 60% of the capacity of Unified Energy Systems of Ukraine, provided 42 – 44% of the total electricity production, and were the primary means of regulating the energy consumption schedule, while anthracite power units represented more than half of the generation capacity of TPPs.

However, this situation changed dramatically with the military operations in the east of the country and the subsequent limited supply of Donetsk anthracite and lean coal. In 2017, with complete cessation of supplies of low-volatile coals from Donbass, the task of converting one or two power units at each of the anthracite TPPs to the combustion of gas coal became relevant, as production continued and even increased in Western Donbass, the Dnipropetrovsk oblast', and the Lvov – Volyn' hard coal basin.

By that time, two TP-100 anthracite boilers with 200 MW power units at the Zm³ivs'ka TPP of the Tsentrénergo PJSC company had already been converted to gas coal (KhPKI TÉP-Soyuz LLC, Kotloturboprom LLC, Ukraine, Kharkov, 2016 – 2017) through the use of drying and transport of dust to the burners with a mixture of flue gases and air with an oxygen content of less than 16%. For this purpose, in accordance with the recommendations [1], each of the two pulverized-coal systems of the boiler was equipped with a gas recirculation fan, two external cyclones for cleaning flue gases taken for drying from the convection shaft behind a water economizer, and a new mill exhauster fan to produce a speed of not less than 25 m/sec for the air-fuel mixture in the pulverized-coal ducts. The boiler was equipped with an additional smoke exhauster for inert gases taken after the main smoke exhauster to ensure the operation of the mills in startup and shutdown modes, and new swirl burners with an adjustable degree of secondary air swirling.

In general, the specific capital costs amounted to US$16 – 18 per 1 kW of the rated electric power for the implementation of measures for only the boiler, not including the organization of separate storage of different grades of coal in the warehouse, additional fire-prevention measures, and the automated technological process control system.

After the reconstruction, the boilers worked reliably. However, because it largely depleted the investment opportunities of Centreenergo for 2017, for the conversion to gas goal of the No. 3 and 4 TPP-210A boilers with 300 MW power units at the Tripillya thermal power plant, the reconstruction cost was reduced through the maximum use of existing equipment.

Boilers and their pulverized-coal systems before reconstruction. The TPP-210A boiler is a two-body, symmetrical system connected to the turbine according to the

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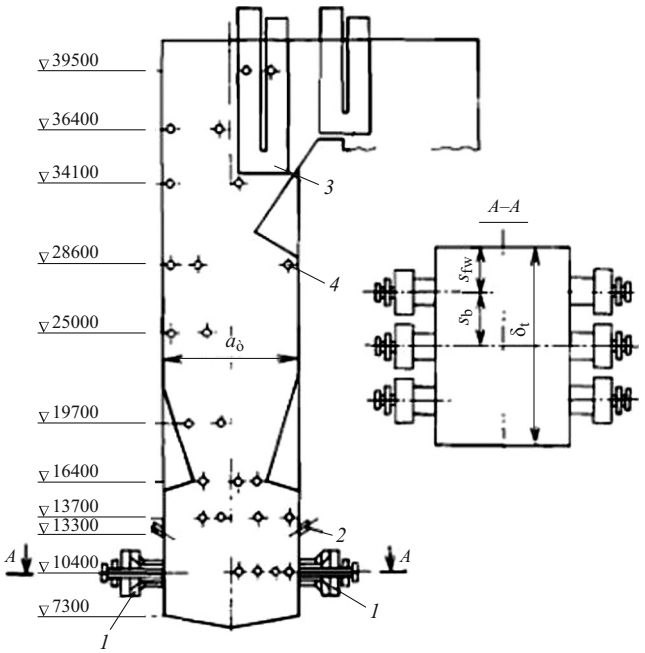

Fig. 1. TPP-210A boiler scheme (one furnace): *1*, main burners; *2*, supplementary-fired burners; *3*, screens; *4*, hatches for measurements.

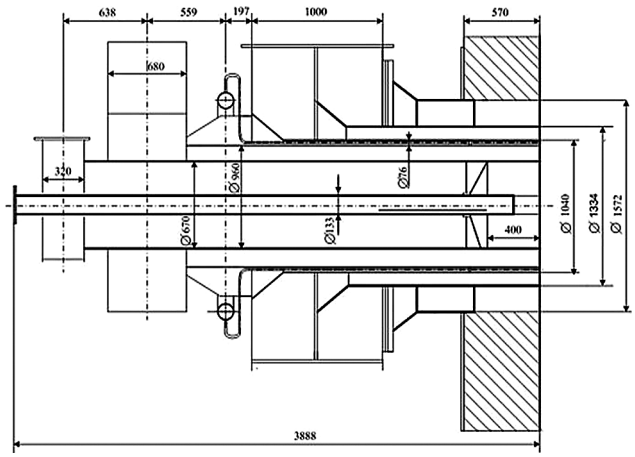

Fig. 2. Main burner of the TPP-210A boiler.

double-block scheme. Each body (Fig. 1) is an independent unit with a U-shaped layout with a steam-generating capacity of 475 tons/h. The walls of the furnace are shielded by pipes with radiant heating surfaces. The protrusions formed by the front and rear screens create a bend that divides the furnace into two chambers, for combustion (an extended furnace) and cooling. The screens are studded ahead of the bend and covered with silicon carbide, which helps to reduce heat losses from the flame kernel and to maintain the temperature regime for liquid slag removal. The thermal stress of the volume at the rated load is 0.54 MW/m^3 for the extended furnace and 0.173 MW/m^3 for the entire furnace. Steps 1 and 2 of the screen heating surfaces are located in the upper part of the furnace and in the pivotable chamber, respectively. In the descending convective shaft, there is a convective step of the primary superheater, a secondary superheater, and a water economizer, and after the bend, there is an electrostatic precipitator and a smoke exhauster. The design parameters of the working steam are 25 MPa and 565°C. Because of a 1971 directive to decrease the temperature of working and secondary steam to 545°C in the boilers of unit Nos. 3 and 4, the screening steam superheaters of step 1 were not initially installed, which reduced the amount of injections and the risk of slagging of the screens.

Each combustion chamber is equipped with six scroll blade burners, which are single-channel for primary air and two-channel for secondary air (Fig. 2) and are installed in one tier on the front and rear walls. Straight-flow waste nozzles are located approximately 3 m above each burner.

The boiler is equipped with three closed pulverized-coal systems with ball-drum mills BDM-50A with an anthracite capacity of 50 tons/h, separators, cyclones, mill exhauster fans, and a common dust bin (Fig. 3). The rated capacity of the VM-160/850 mill fan is 180,000 m^3/h and the actual capacity is 130,000 m^3/h. A feature of the TPP-210A boilers at Tripillya TPP is the transport of dust to the main burners via high-concentration pulverized-coal ducts under pressure, which are connected to the primary air pipelines 2 – 3 m in front of the burners. Air is supplied to air-assisted feeders and dust transport is provided by a TV-80-1.8-01 turbo-compressor with a flow rate of 6,000 m^3/h under a pressure of 0.18 MPa. Air is supplied to the main burners from two hot-blast fans VGD-20U with a nominal capacity of 150,000 m^3/h and an actual capacity of approximately 130,000 m^3/h.

Initially, the design fuel for the boiler was Donetsk anthracite with a calorific value of 6050 kcal/kg and Donetsk lean coal with a calorific value of 6500 kcal/kg. In fact, in the 1980s-1990s, high-ash Donetsk anthracite was burned on boilers with a calorific value of 4100 – 4800 kcal/kg and a gas-oil illumination of 35 – 45% in terms of heat, while during the last 15 years, a mixture of anthracite and lean coal with a calorific value of 5200 – 5800 kcal/kg without illumination has been used.

Technical solutions and results of the reconstruction of the boiler of unit No. 4[3]. When analyzing possible options for converting to gas coal, the option of maintaining the existing air-drying scheme and reducing the temperature of the air-fuel mixture behind the mill to less than 70°C was considered unacceptable because of insufficient guarantees of explosion and fire safety, the risk of moisture condensation at high volume of the pulverized-coal system elements, and the lengths of the pipelines. The option of using equipment with medium-speed mills with direct injection of dust

[3] Technical solutions for the boilers of units No. 3 and 4 were developed by CETI NAS of Ukraine, technical and detailed reconstruction projects were developed by Spetstermomontazh-Énergo LLC (Kiev) and KhPKI TÉP-Soyuz LLC (Kharkov).

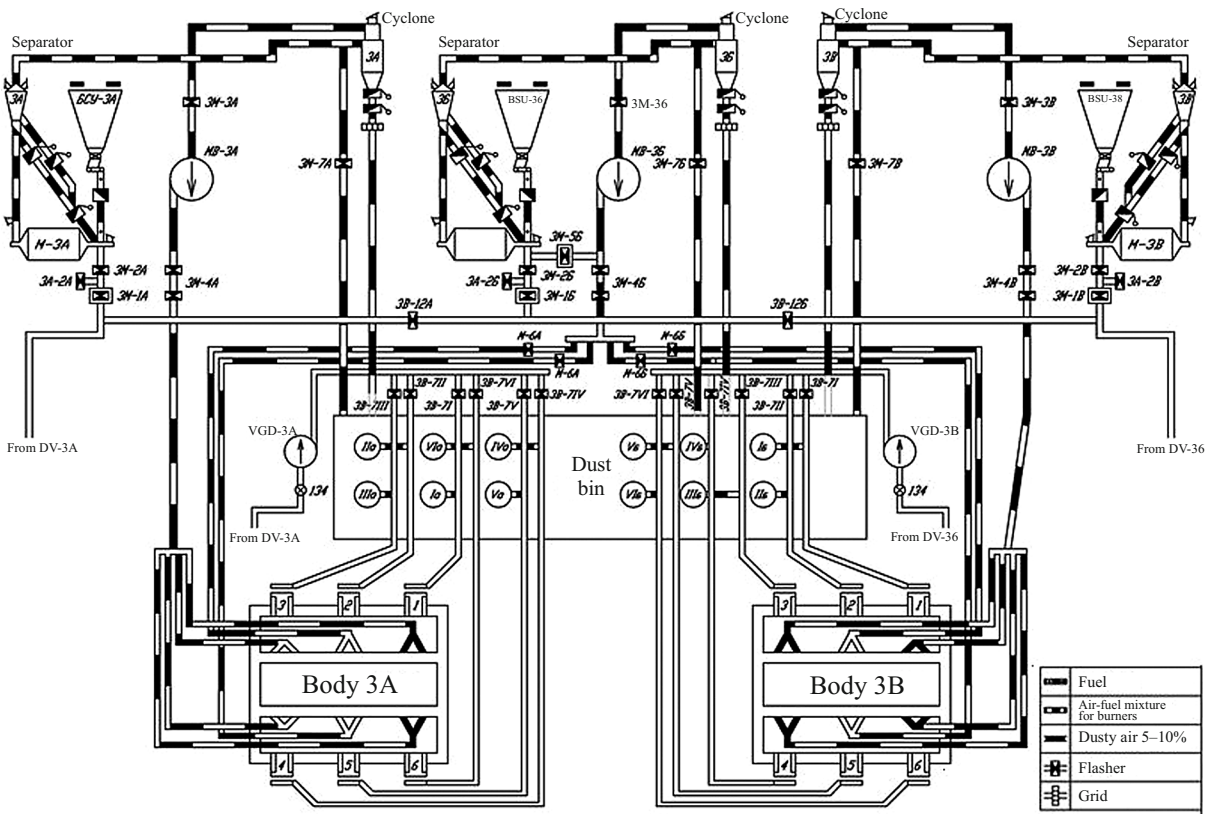

Fig. 3. Pulverized-coal systems of the TPP-210A boilers of units No. 3 and 4 before reconstruction.

into the burners was also considered unacceptable because of its high cost and the time taken to manufacture the mills. The "classic" version, similar to that used on the 200 MW units at the Zm³ivs'ka TPP, was also considered unacceptable because the large amount of work required and the cost of additional equipment.

On the other hand, for gas coal with a calorific value of 4950 – 5350 kcal/kg, a moisture content of 7 – 15%, and a grindability 30% higher than that of anthracite, the consumption-heat calculations showed the possibility of achieving the nominal boiler output during operation on two pulverized-coal systems. At the same time, it was found that to ensure the temperatures of the air-fuel mixture behind the mill remained at 85 – 105°C, the required flow rate of the mill fan can be no more than 125,000 m^3/h, which enables use of the existing mill fans, and the required flow rate of the flue gases for one pulverized-coal system with an oxygen content of less than 16% can be no more than 122,000 m^3/h, which enables use of existing hot-blast fans as smoke exhausters for recirculation of flue gases. In turn, the latter enables use of compact ash concentrators (Fig. 4) instead of bulky external cyclones for ash cleaning of the flue gases taken (Fig. 4), by placing them in the existing gas passages.

Another original technical solution aimed at reducing the cost of reconstruction was the use of inert gases instead of the smoke exhauster to reduce the temperature of the aerating medium in the compact injection gas coolers with a maximum water flow rate of 2.5 tons/h, which is significantly less than the consumption of moisture evaporated from coal, during both startup and shutdown of pulverized-coal systems. To ensure operation for partial loads with high-calorific and/or low-moisture coals, the drying agent recirculation system was restored from the mill fan outlet to the mill

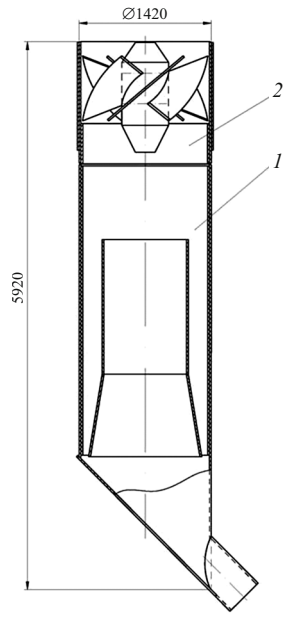

Fig. 4. Longitudinal section of the ash concentrator: *1*, vane swirler; *2*, separator of dust-laden and cleaned flows.

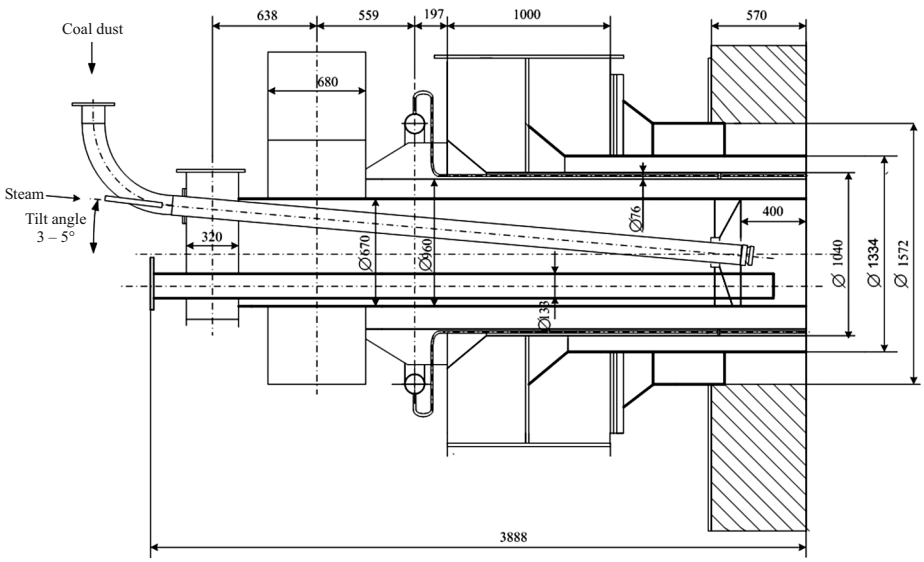

Fig. 5. Upgraded TPP-210A boiler burner with insertion of a dust pipe and steam ejector into the central channel.

inlet, and to increase safety in case of separate startup and shutdown of the boiler bodies, the dust bin was separated with a gas-tight vertical partition into two parts, corresponding to the boiler bodies.

For many years, the high-concentration dust supply system under pressure in the boilers of the Tripillya TPP has demonstrated ease of use and high wear resistance. However, its application to gas coal is limited by the risk of air filtration into the dust bin through the air feeders, especially in the case of clogged pulverized-coal ducts and/or when the dust level in the bin is low. In addition, in the case of gas coal, the connection of high-concentration pulverized-coal ducts 2 – 3 m in front of the burners is an additional risk factor for self-ignition of dust even before it enters the burner, and the supply of dust into the primary air duct with a scroll twist is a risk factor for excessive shortening of the flare up to burning of the burner face.

On the other hand, for the TP-100A boilers of the Burshtyn TPP, the scheme for transporting high-concentration gas-coal dust under rarefaction using a steam ejector placed directly in the central channel of a straight-flow burner has shown its effectiveness for many years [2]. Taking this into consideration, for the boiler of unit No. 4 of the Tripillya TPP, a comprehensive technical solution was adopted that includes[4]:

— a dust bin with ULPP-2-64I blade feeders with a capacity of 12 tons/h and dust mixers placed under them with a cold-air suction device;

— transport of dust to the front burners through high-concentration pipelines (without insulation) with a diameter of 102 × 6 mm and to the rear burners through pipelines with a diameter of 108 × 6 mm;

— dismantling of the twist blades in the central channel of the burners and moving the existing fuel-oil injectors downward relative to the central channel axis;

— input of dust into the central channel of the existing burners by means of a pipe, which has an inlet equipped with a steam ejector with a contracting-expanding nozzle and an outlet comprising a tapered splitter of the dust flow (Fig. 5); and

— deepening the ends of the burner channels by 0.35 m in accordance with recommendations [3, 4] to protect against burning-out, taking into account the shorter length of the gas-coal flame.

Steam is supplied to the contracting-expanding nozzles with a pressure of 1.3 – 2.0 MPa and a temperature of 350 – 400°C from the output manifolds of the first stage of the intermediate superheater (at startup from the auxiliary collector of the unit). Steam consumption is 160 – 180 kg/h for one front burner and 220 – 250 kg/h for one rear burner and the rates of the air-fuel mixture in the pulverized-coal ducts are 10.5 and 9.2 m/sec, respectively.

When coal dust is fed into the central channel with dismantled twist blades, the swirl burner becomes a straight-flow swirl burner, the central channel performs the function of a primary straight-flow air channel, and the primary air channel performs the function of the first secondary air channel with a scroll swirler. Its twist parameter (3.5 – 4.0) corresponds to the twist parameter recommended in [3, 4] for straight-flow swirl burners for burning gas coal with liquid slag removal.

During the reconstruction of the boiler of unit No. 4, the recommended [5] scheme with exhaust drying agent supplied to the main burners was adopted. This solution enabled the excess air ratio in the main burners to be increased to 1.15. Considering that the mutual arrangement of air ducts, drying-agent discharge pipelines, and burners makes the sup-

[4] The system for supplying high-concentration dust under rarefaction was developed by M. Klub (Spetstermontazh-Énergo LLC).

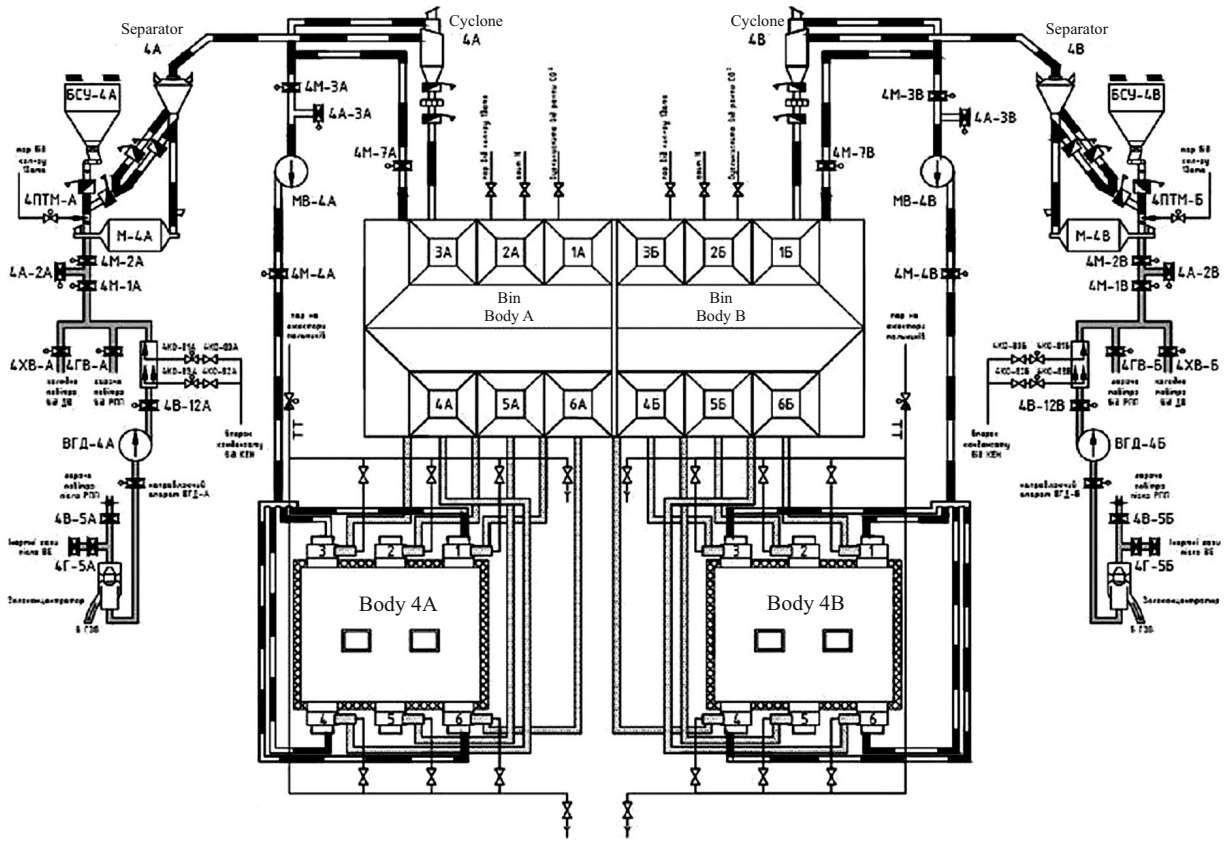

Fig. 6. Diagram of the pulverized-coal system of the TPP-210A boiler of unit No. 4 after reconstruction.

ply of the exhaust drying agent to the central channels extremely complicated, it was decided to direct it into the existing primary air channels. The difficulty lay in the fact that the pulverized-coal system had an extension for four drying-agent discharge channels and there are six main burners on the body. Hypothetically, it would be possible to make an extension for the six discharge channels with a decrease in the diameter of the discharge pipelines in order to maintain a flow rate in them of more than 25 m/sec, but then the flow rates in the primary air channels would decrease by 1.5 times.

Therefore, it was decided to supply the exhaust drying agent to the primary air channels of the four extreme burners of each body and hot air to the primary air channels of the middle burners. This enabled the velocities in the central, primary, and secondary air channels to be increased to 22, 24, and 28 m/sec, respectively, which also corresponds to the recommendations [3, 4] for straight-flow swirl burners. A diagram of the TPP-210A boiler pulverized-coal system of unit No. 4 after reconstruction is presented in Fig. 6.

Thermal calculations of the calibration zones of the furnace chambers were conducted according to the method [6] for gas coal with a calorific efficiency of 4950 – 5350 kcal/kg, a moisture content of 7 – 15%, and ash melting temperatures t_A = 1230 – 1285°C, and t_C = 1300 – 1450°C. They showed that, despite an increase in the consumption of flue gases by 10 – 12% due to the specific consumption of combustion products of gas coal, which are higher in comparison with anthracite, and recirculation of flue gases for drying fuel, the temperature at the outlet of the combustion chamber at a nominal load is approximately 1550°C, which provides a stable liquid-slag removal mode, and the temperature at the outlet of the furnace is no more than 1130°C, which prevents slagging of screens.

After the reconstruction, which, together with design stage, lasted for 7 months, the power unit was commissioned at the end of January 2018. Due to the use of original technical solutions with the maximum use of existing equipment, the specific capital expenditures did not exceed US$3.5 per 1 kW of installed power capacity.

Tests of the reconstructed boiler have shown the stability of the liquid-slag removal mode and the absence of slagging of screens in the load range of 70 – 100%. Compared to anthracite, which has losses due to unburned matter of 6.0 – 6.5% and an efficiency (gross) of 82.5 – 83.0%, the technical and economic parameters of the boiler were significantly improved, with losses due to unburned matter of 1.0 – 1.2% and an efficiency (gross) of 87.0 – 87.5%. A further increase in efficiency (gross) is possible with a decrease in suction in the convection shaft and overflows in the regenerative air heater, but funds were not allocated during the reconstruction. Due to the decrease in the average furnace temperature and the

supply of steam from the ejector to the base of the flame, in comparison with the combustion of anthracite, the emission of nitrogen oxides has decreased by 15 – 20%.

Until the end of 2018, the power unit operated for 7360 h, including 1560 h in a single-body mode, with an average load of the body of 77% and an average efficiency (gross) of 86.9% (taking into account startup losses). There were frequent cases when, due to the lack of fuel for anthracite power units, unit No. 4 functioned as one body for the entire TPP, which indicates its high reliability and safety in operation. In 2019, the power unit operated for 6070 h, including 1400 hours in a single-body mode, with an average load of the body of 75% and an average efficiency (gross) of 86.4%.

Technical solutions and results of reconstruction of the boiler of unit No. 3. Technical solutions for the reconstruction of the boiler of unit No. 4 were used as a basis for the reconstruction of the boiler of unit No. 3. The only fundamental change concerned the discharge of the exhaust drying agent.

Although the scheme with the supply of the exhaust drying agent to the extreme main burners has demonstrated its effectiveness in forming a flare of optimal length and in the completeness of dust burnout, it turned out to be rather complicated in operational regulation. Firstly, due to the residual dustiness of the exhaust drying agent with the same efficiency of the pulverized-coal feeders, the dust consumption for the extreme burners turned out to be 10 – 15% higher than for the middle ones, which required separate regulation of the pulverized-coal feeders to equalize the dust consumption in the burners. Moreover, when the load changed, the oxidizer flow rate into the primary air channel of the extreme burners remained constant, according to the operating conditions of the mills, and supply into the primary air channel of the middle burners either changed in proportion to the total flow rate of the blast air or else required additional regulation. Taking this into account, the plant specialists considered the possibility of preserving the discharge of the exhaust drying agent into the existing supplementary-fired burners.

It is usually believed that the presence of supplementary-fired burners during the combustion of gas coal leads to pulling of the flare, owing to the ingress of some of the dust with a drying agent into the upper part of the combustion chamber, and, as a consequence, to an increase in the temperature of the flue gases and to conditions of screen slagging. However, a detailed analysis of the literature on this issue, in particular, the results of tests when burning gas coal in TP-100A boilers with supplementary-fired burners [4], showed that the reason for this pulling is quite different, namely, the lack of oxidizer in the main burners due to the supply of a significant part of the oxygen required for combustion to the supplementary-fired burners. At the same time, the consumption-heat calculation of the pulverized-coal system shows that when converting the TPP-210A boiler to gas coal, this negative phenomenon can be avoided.

Indeed, when burning anthracite in a TPP-210A boiler with three pulverized-coal systems and a mix of air and drying agent, almost 30% of the stoichiometrically required air is supplied to the supplementary-fired burners, which, taking into account the cold air suction into the furnace of 5 – 7%, reduces the excess air coefficient on the main burners to 0.82 – 0.85. However, when converting to gas coal, the number of pulverized-coal systems is reduced to two, which reduces the consumption of discharged drying agent by 1.5 times. In addition, instead of air, a mixture of air with flue gases with an oxygen content of approximately 15% was used as a drying agent, which reduces the amount of discharge oxidizer by another 1.4 times, which is generally more than twice that of the combustion of anthracite. Therefore, when the drying agent is discharged to the supplementary-fired burners, the oxidizer flow rate to the main burners is close to stoichiometric, and taking into account the supply of only dust caught by cyclones (85 – 90% of all dust), the excess air ratio on the main burners reaches 1.15 – 1.18.

To simplify the trace on the boiler of unit No. 3, a scheme with discharge of the exhaust drying agent into the extreme supplementary-fired burners was chosen, while the middle supplementary-fired burners were shut off. Hot air was supplied to the primary air channels of all main burners, and to maintain increased gas velocities in the burner channels, in accordance with the recommendations for gas coal, their external secondary air channels were transferred to the mode of a protective cooling blast. Such a scheme (Fig. 7) simplifies the design of the inputs to the main burners and greatly facilitates the regulation of the main burners in case of a unit load change.

When performing thermal calculations for the verification zone of the furnace for this scheme, the calculation method was adjusted relative to the recommendations [6] by dividing the combustion chamber into two zones and taking into account the different ratios of consumption of dust and oxidizer in the zones of the main and supplementary-fired burners. Calculations have shown that the gas temperatures at the combustion chamber outlet and at the furnace outlet have insignificant changes compared to the scheme with the drying agent discharged to the main burners, but at the same time the adiabatic combustion temperature is increased by 50°C, providing a significant reserve according to the temperature regime of liquid slag removal, especially at the low loads of the boiler.

After the reconstruction, which, together with design stage, lasted for 6 months, the power unit was commissioned in January 2019. Tests of the reconstructed boiler revealed the stability of the liquid-slag removal mode and the absence of slagging of screens in the load range of 65 – 100%. The technical and economic parameters of the boiler were the same as those of the boiler of unit No. 4; compared with combustion of anthracite, the release of nitrogen oxides was decreased by 10 – 15%. Until the end of 2019, the power unit operated for 5980 hours, including 1670 hours in a single-body mode, with an average load of the body of 76% and an

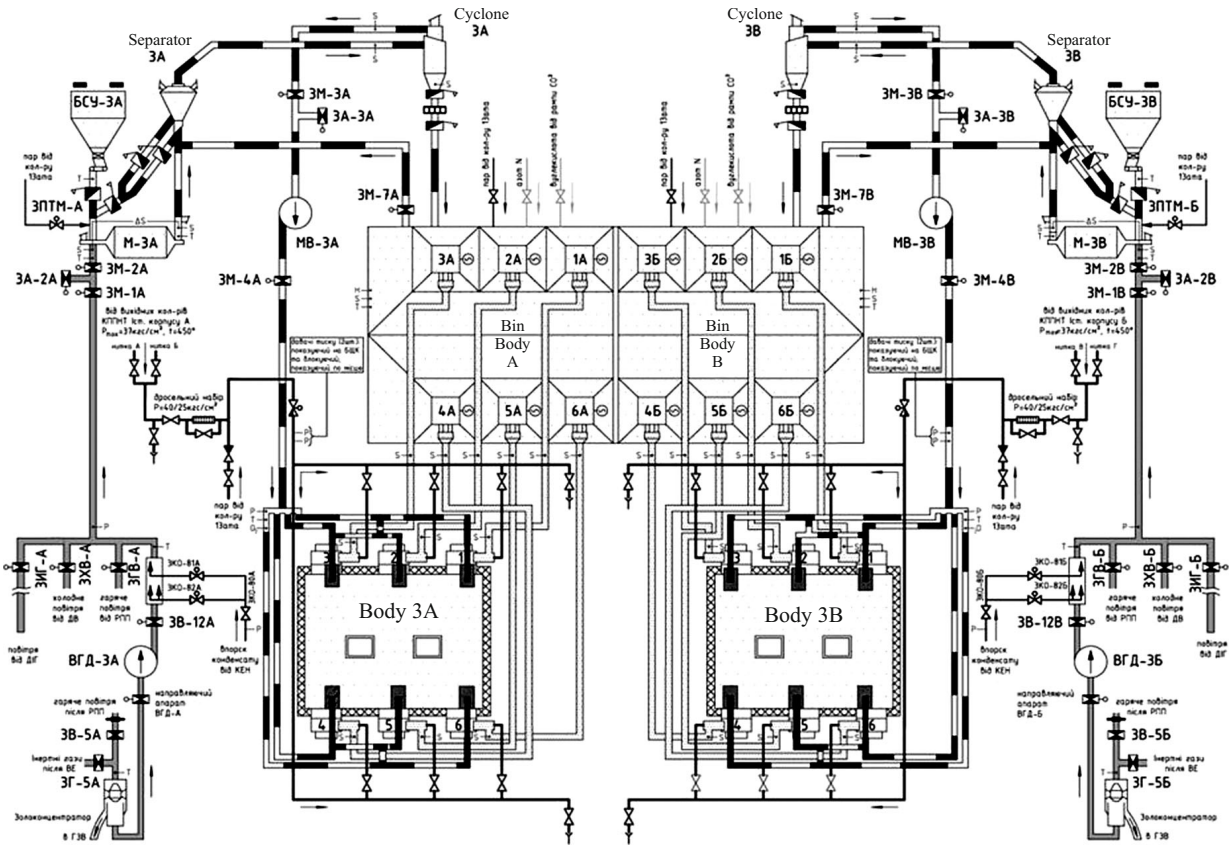

Fig. 7. Diagram of the pulverized-coal system of the TPP-210A boiler of unit No. 3 after reconstruction.

average efficiency (gross) of 86.2% (taking into account losses for startup).

The only shortcoming of the gas-coal combustion scheme with supplementary-fired burners is that when the level of cold air suction into the furnace is more than 10% at high loads, the excess air coefficient on the main burners decreases to less than 1, and in turn the CO content in the combustion products the increases. Therefore, the actual load of the unit of No. 3 had to be limited to 90% of the nominal value. However, when the level of suction is adjusted to the standard value, this negative phenomenon is eliminated.

Possibility of reverse transition to combustion of low-volatile coal. In autumn of 2019, due to the introduction of the energy market and the inconsistency of market rates for electricity supply and the cost of coal production, Ukraine faced a temporary shortage of locally produced gas coal. By that time, there was a sufficient volume of imported lean coal in the Tripillya TPP warehouse.

Under these conditions, at the request of the TPP, specialists from the Coal Energy Technology Institute of the National Academy of Sciences of Ukraine, based on a computational study and taking into account the specified margin for the adiabatic combustion temperature, justified the possibility of combustion of lean coal in the boiler of unit No. 3 without changing the composition of the equipment, but using only mode measures (thinning the dust grinding, switching to hot-air drying, increasing the temperature of the air-fuel mixture behind the mill from 85 – 90°C to 95 – 105°C, and reducing the proportion of primary air to shorten the flare length).

Tests performed in the calculated modes of coal pulverization and combustion have shown the stability of combustion and liquid slag removal of lean coal with a calorific efficiency of 5800 – 6000 kcal/kg in the bin load range of 70 – 100% with losses due to unburned matter of 3.0 – 4.0%. Thus, the coal-based 300 MW power unit of the Tripillya TPP unit No. 3 became the first in the world capable of operating on two fundamentally different types of fuel, gas coal and lean coal.

CONCLUSIONS

The original technical solutions developed by the Coal Energy Technology Institute of the National Academy of Sciences of Ukraine for the conversion of TPP-210A anthracite boilers with 300 MW power units of the Tripillya TPP to burning gas coal with the maximum use of existing equipment ensured reliable and safe operation of the boilers while reducing the cost of reconstruction by 4 – 5 times compared with traditional solutions and a significant improvement in the technical, economic, and environmental parameters of boilers compared to combustion of anthracite.

The most crucial of these is the supply of dust to the main burners under rarefaction using steam ejectors, and most novel is the technical solution used on the boiler of unit No. 3 for the preservation of supplementary-fired burners. Such a scheme provides a margin for the adiabatic combustion temperature, which expands the range of regulation of the unit load when burning gas coal and enables switching from gas coal to lean coal and back without changing the composition of the equipment, but by only changing the operating parameters of coal pulverization and combustion.

The results of the conversion of the TPP-210A boilers to combustion of gas coal as part of the work of the Coal Energy Technology Institute of the National Academy of Sciences of Ukraine's "Scientific Foundations and Implementation of Innovative Technologies for Replacing Anthracite in Thermal Power Industry" were awarded the State Prize of Ukraine in the field of science and technology in 2019.

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