Reconstruction of the tail heating surfaces of CHP boilers in order to improve the efficiency

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Abstract. Recently, the share of non-design fuel use of coal at thermal power plants has increased, which negatively affects the operation of existing equipment. On the territory of the Irkutsk Region, there are 9 combined heat and power plants operating mainly on brown coals of the Irkutsk and Kansk-Achinsk basins. The main fuel at many CHPs is brown coal from the Mugunskoye deposit, the quality of which is deteriorating year by year. At the Novo-Irkutsk CHP, there is a prospect of continuing the supply of the Mugunsky coal with a sulfur content of up to 2.5%, which significantly exceeds the sulfur content of the design coals, which is 0.5%. This leads to the condensation of sulfuric acid vapors in the flue gases and, as a result, the heating surfaces are subject to sulfuric acid corrosion. In addition, there is a problem of erosive wear of air heaters at CHPs, caused by high flow rates and ash concentrations, which is also caused by a deterioration in the composition of the burnt coal. To solve the problem associated with low-temperature sulfuric acid corrosion of the boiler air heater tanks, it is proposed to place additional heating surfaces in the bypass gas ducts, which will reduce the temperature of the gases by cooling the flue gases with network water, and allow the obtained heat to be used in the added sections of the calorifier for heating the inlet (cold) air. While bypassing 25% of gases using the heat of gases in the calorifiers, erosion wear is reduced due to a decrease in the gas velocity in the air heater from 13 m/s to 9 m/s. The proposed technical measures will make it possible not only to increase the efficiency of the boiler and the plant as a whole, but also to increase the degree of fuel heat use.

At present, a stable tendency of deteriorating the quality of fuel supplied to thermal power plants (TPPs) has been formed. TPPs face a difficult task of efficient combustion of design grade coals with deteriorated quality characteristics and non-design coals [1]. Therefore, work aimed at determining the conditions under which the use of such coals at TPPs can be cost-effective is becoming especially relevant today.

So, for example, the problem of erosive wear and low-temperature sulfuric acid corrosion of the boiler tubular air heater (TAH) tanks is urgent at station No. 8 of the Novo-Irkutsk CHP due to the use of non-design fuel with an increased ash content and a high sulfur content of the coal from the Mugunskoye field on the E-820-13.8-560BT boiler. Especially acute is the problem of erosive wear of the air heater, which is caused by high flow rates and ash concentrations. Also, the combustion of non-design fuel with a high sulfur content leads to condensation of sulfuric acid vapors and, as a result, heating surfaces are subject to sulfuric acid corrosion [2-4]. Increased gas velocities in TAH and sulfuric acid corrosion reduce the service life of the heating surface and require measures to improve the efficiency of the boiler back-end surfaces [5-8]. It should be noted that corrosion and erosion processes

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on the outer surface of pipes depend on the fuel used by the boiler and the composition of the gaseous combustion products [9]. The problems under consideration are relevant, which is confirmed by numerous studies; some of them are given in [2,10-15].

The intensity of erosion mainly depends on the velocity of flue gases. To date, the gas velocity in the TAH shaft is 13 m/s, which is higher than the recommended one for fuels with increased ash content and ash abrasiveness. Reducing the velocity is a necessary measure to combat this problem. This is possible due to a decrease in the volume of flue gases passing through the boiler TAH by bypassing the fraction of gases. To minimize the uneven distribution of gases along the inlet section of the boiler TAH, it is most acceptable to install two bypass gas ducts, to the right and left of the TAH. Since the gases in front of the TAH have a sufficiently high temperature of 263°C, bypassing the gases is economically feasible only when the heat of the flue gases is used for own needs or outside the boiler.

The problem of low-temperature sulfuric acid corrosion of the boiler TAH tanks may be solved by placing additional heating surfaces (AHS) in the bypass gas ducts, which will reduce the temperature of the gases by cooling the flue gases with network water, and allow the obtained heat to be used in the added sections of the calorifier for heating the inlet (cold) air. The removed heat in AHS together with the use of a cascade air heating circuit will increase the temperature of the inlet air and reduce the heat transfer coefficient from the air to the tube wall, which will ensure the maintenance of the temperature of the boiler TAH metal wall above the dew point and, as a result, will help reduce sulfuric acid corrosion.

It should be noted that the proposed technical measures are limited by a number of factors:

- a decrease in the gas velocity in the TAH to the standard 7-7.5 m/s requires bypassing a larger proportion of flue gases (up to 40%) and leads to the need to utilize excess heat. The use of additional heat outside the boiler is limited by the specifics of the equipment location and the heat balance diagram of the CHP. As a result, the use of an increased bypass proportion (up to 40%) on the boiler is impossible;
- an increase in the proportion of bypassing and an increase in the heating surface of the AHS is restrained by the boiling-up conditions of the heat transfer medium;
- an increase in the flow of network water entails a significant increase in hydraulic resistance;
- the use of excess heat to heat the own air also has its limitations. Thermal calculations showed that an increase in the flow area and an increase in the surface of the calorifiers do not increase the heat removal due to a decrease in the air velocity. An increase in heat removal can be achieved only by building up the surface along the direction of air movement (increasing heating steps), which is limited by the fan pressure;
- an increase in the temperature of the TAH metal wall due to an increase in the temperature of the inlet air and the use of a cascade heating circuit is restrained by an increase in the temperature of the exhaust gases and a decrease in the air temperature behind the TAH;
- the efficiency of AHS is limited by sulfuric acid corrosion of heating surfaces, therefore, the temperature of the network water at the AHS inlet should be at least 130°C (above the dew point);
- in order to avoid boiling-up of the heat transfer medium, the pressure behind AHS should provide a temperature margin above the saturation point of at least 10°C;
- calorifier sections have a non-standard location, since they are located at an acute angle to the flow, which requires the development of a correct calculation method for accurately determining the aerodynamic resistance and checking the presence of a fan blast margin;
- an increase in the temperature of the return water network circuit (behind the calorifier) reduces the thermal efficiency of the network circuit.

To determine a more rational scheme, we analyzed several options for the arrangement of calorifiers (table 1) and a number of calculations performed with a change in the main influencing parameters of the system (tables 2-4).

Taking into account all the requirements, as a compromise solution, we took a bypass of 25% of the total gas flow rate with a decrease in the gas velocity in the TAH to 9 m/s. The given gas velocity in the THP ensures the optimal operation of the E-500-13.8-560 BT boilers operated at the Novo-Irkutsk CHP. According to the terms of reference, the gas velocity in the TAH should be no more than 9 m/s.
### Table 1. Arrangement of calorifiers.

| Parameters                                      | Scheme of the work |
|------------------------------------------------|--------------------|
|                                                | 81 calorifiers 3 steps | 54 calorifiers 2 steps | 54 calorifiers 2 steps | 54 calorifiers 2 steps |
| Gas flow through the bypass, %                 | 35-40              | 35-40              | 35-40              | 20-25              |
| Water flow, t/h                                | 400                | 400                | 250                | 250                |
| Water temperature behind AHS, °С               | 150                | 150                | 160                | 151                |
| Return water temperature, °C                   | 116                | 121                | 113                | 108                |
| Air temperature behind TAH, °C                 | 133                | 119                | 121                | 118                |
| Hot air temperature behind TAH, °C             | 213                | 212                | 212                | 218                |
| Exhaust gas temperature, °C                    | 158                | 152                | 154                | 156                |

### Table 2. Change in the proportion of bypass and gases through AHS.

| Parameters                                      | Change in gas flow through AHS                     | Change in bypass proportion |
|------------------------------------------------|---------------------------------------------------|-----------------------------|
| Cascade                                        | 65/20/15                                          | 55/20/25                    |
| Water temperature before AHS, °С               | 130 130 130 130                                    | 130 130 130 130             |
| Water temperature after AHS, °C                | 151 153 155 156                                   | 151 151 151 151             |
| Water temperature behind the calorifier, °C    | 108 109 110 111                                   | 113 111 108 106             |
| Water flow for calorifiers, t/h                | 250 250 250 250                                    | 250 250 250 250             |
| Gas flow through the bypass, %                 | 25 28 31 34                                       | 25 25 25 25                |
| Air temperature at the TAH inlet, °C           | 118 119 121 22                                    | 122 120 118 116             |
| Metal wall temperature min, °C                 | 130 129 130 130                                   | 133 132 130 128             |
| Hot air temperature, °C                        | 218 216 213 211                                   | 210 214 218 222             |
| Gas velocity in TAH, 2 max, m/s                | 9.2 9.2 8.8 8.4                                    | 9.5 9.6 9.2 (9.7<sup>a</sup>)|
| Gas temperature behind AHS, °C                 | 190 193 195 197                                   | 190 190 190 190             |
| Exhaust gas temperature, °C                    | 156 157 158 159                                   | 158 157 156 156             |

<sup>a</sup> Maximum gas velocity.

### Table 3. Change in the flow and temperature of the network water.
Bypassing 25% of the total gas flow rate, as can be seen from the table, allows obtaining the optimal gas velocities in the TAH and reduce the excess heat from AHS. In this case, the water after the boiler calorifiers returns to the return water collector with a temperature of 105-115 °C.

The air in the calorifiers is heated to a temperature of 115-120°C, which, when combined with cascading, eliminates the corrosion of the TAH.

As shown by a number of calculations, as well as operating calculations at loads of 60% and 100% of the nominal load D_{nom} (table 4), the system parameters are retained when the steam capacity changes (temperature of hot air and exhaust gases) and deteriorate when the proportion of bypass and cascade

### Table 4. Summary table of the results of thermal calculations.

| Parameters | Change in the temperature of the network water at the inlet to AHS | Change in the flow of the network water |
|------------|---------------------------------------------------------------|----------------------------------------|
| Cascade   |                                                                 |                                        |
| Water temperature before AHS, °C | 130 120 110 110 | 130 130 130 130 |
| Water temperature after AHS, °C | 151 143 135 126 | 164 156 151 148 |
| Water temperature behind the calorifier, °C | 108 103 97 92 | 93 102 108 112 |
| Water flow rate for calorifiers, t/h | 250 250 250 250 | 150 200 250 300 |
| Gas flow rate through the bypass, % | 25 25 25 25 | 25 25 25 25 |
| Air temperature at the TAH inlet, °C | 118 112 106 100 | 117 118 118 118 |
| Metal wall temperature min, °C | 130 124 120 115 | 129 130 130 130 |
| Hot air temperature, °C | 218 218 218 218 | 218 218 218 218 |
| Gas velocity in TAH, 2 max, m/s | 7.8 9.2 (9.7) | 9.2 (9.7) |
| Gas temperature behind AHS, °C | 190 184 179 174 | 193 191 190 189 |
| Exhaust gas temperature, °C | 156 153 149 145 | 157 157 156 156 |

* Maximum gas velocity.
transfer changes. In this connection, the scheme does not provide for automatic adjustment of the latter, and adjustment is carried out by changing the parameters of the network water at the inlet to AHS.

Structurally, an AHS is a panel gas duct rectangular in cross section with a heating surface located inside. The main design characteristics of AHS are given in table 5.

| Parameter                                 | Value  |
|-------------------------------------------|--------|
| Standard size of heating surface pipes, mm| 28×3   |
| Steel grade of AHS coils                  | Steel 20 |
| Steel grade of AHS fencing panels         | Steel 3sp |
| Block weight, kg                          | 10392.6|
| Heat exchanger aerodynamic resistance, Pa | 425    |

AHS consists of 37 parallel packages of pipes Ø28×3, the arrangement of the coils in the AHS is staggered, with transverse $S_1 = 120$ mm and longitudinal steps $S_2 = 55$ mm.

A three-dimensional model of the AHS heat exchanger is shown in figure 1.

![Figure 1. Three-dimensional model of a heat exchanger (AHS) for the E-820-13.8 560BT boiler of the Novo-Irkutsk CHP.](image)

Due to the low temperatures of flue gases in the bypass gas ducts of the TAH, steel 3 was chosen as the material of the AHS fencing panels. Heat exchanger coils, AHS collectors, are made of steel 20 GOST 8731.

Each bypass gas duct is a vertical downward gas duct with a flow area of 2230×4490 mm. The gas duct fencing has a design similar to the AHS unit with dimensions not exceeding vehicle dimensions. The cross-section of the downstream gas ducts is selected based on ensuring an acceptable value of aerodynamic resistance in the duct, taking into account the margin for valve adjustment.

The network pipelines are designed to transport water from the existing collectors of direct network water to AHS and calorifiers of the E-820-13.8-560BT boiler, station No. 8 of the Novo-Irkutsk CHP. Water is supplied from the existing collector to the AHS with a temperature of 130°C and a working pressure of 8 kgf/cm². In the AHS, the water is heated to 150-155°C and sent to the boiler calorifiers, after which it enters the existing return network water collector.
Thus, the proposed technical measures will allow:
- decreasing erosive wear by reducing the gas velocity in the TAH from 13 m/s to 9 m/s by bypassing 25% of the gases, using the heat of the gases on the boiler calorifiers;
- solving the problem of low-temperature sulfuric acid corrosion of the boiler TAH tanks by using the additional heat received in AHS and cascade supply of 35% to the upper stages of the TAH. Air enters the inlet to the first stage of the TAH with a temperature of 115-120°C.

Furthermore, the water after the boiler calorifiers returns to the collector with a temperature of 105-115°C, while the heat in the boiler is not used in full, therefore, it is possible to develop additional measures to fully use the heat from AHS outside the boiler.

Reconstruction of heating surfaces in the boiler unit gas ducts will allow reducing the negative impact from the gas flow, as well as carrying out rational heat exchange in them and increasing the efficiency of the boiler as a whole.

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