Technology of reduction of emissions of nitrogen oxides in power boilers of HPP

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Abstract. A method for reducing the formation of nitrogen oxides in the furnace is described, the feature of which is the use of purging water of the boiler as moisture introduced into the boiler furnace. This makes it possible to reduce the combustion temperature of the fuel in the furnace and prevent the formation of nitrogen oxides. Technologies are proposed that allow introducing purging water into the flue gas recirculation duct and into the furnace of the boiler, and also determining their effectiveness.

1. The effect of nitrogen oxides on the environment

Combustion of organic fuel in boiler installations of heat power plants (HPP) to produce water vapor inevitably leads the release of pollutants and their subsequent release into the atmosphere with flue gases. At the same time, a significant amount of solids (in the form of ash, dust, soot) and gaseous compounds (in the form of oxides of nitrogen, sulfur, carbon, water vapor, etc.) release the environment.

In particular, nitrogen oxides NOₓ, formed at high combustion temperatures in the furnace of the boiler, are substances that carry the greatest danger to the vital activity of humans and other living organisms. According to the State report "On the state and protection of the environment of the Russian Federation in 2015" in 79 cities of Russia, the average annual concentration of nitrogen dioxide (Figure 1) exceeds 1 MAC according to Roshydromet [1].

![Figure 1. The dynamics of emissions of nitrogen oxides in the atmospheric air, kt: — from the stationary sources, — from transport.](image-url)
Nitrogen forms with oxygen a number of oxides, among which it is necessary to isolate nitrogen dioxide (NO₂) – a gas that is noticeable even at a low concentration: it has a brownish-reddish color and a special pungent odor. At a concentration of more than 12 mg / m³ is a strong corrosive substance and highly irritates the nasal cavity and eyes. At a concentration of more than 187 mg / m³ causes bronchitis, and more than 623 mg / m³ – pulmonary edema, even if the effect lasted only a few minutes [2].

There are three mechanisms of formation of nitrogen oxides: thermal, fast and fuel. In the formation of thermal and fast nitrogen oxides, the air is the source of nitrogen, and in the case of the formation of fuel oxides of nitrogen - the nitrogen-containing constituents of the fuel.

During the burning of natural gas, about 25% of the volume of oxides formed in the combustion products are fast oxides of nitrogen, the remaining 75% are thermal oxides. When combusting fuel oil, about 45% of the volume is made up of fuel oxides, 50% of them are thermal oxides, about 5% are fast oxides. When burning coal about 85% are fuel oxides of nitrogen, 0.5% – fast oxides of nitrogen, and 15% – thermal [3].

The content of thermal nitrogen oxides in gaseous fuels reaches 80% of the total emissions. Reducing the temperature of the flame makes it possible to prevent the formation of thermal nitrogen oxides.

The temperature of flame can be reduced in various ways [4]:
1. Reduction of the specific heat load;
2. Special construction of the combustion chamber;
3. Preliminary mixing of air and gas;
4. Stepwise combustion;
5. Recirculation of combustion products;
6. The introduction of moisture into the zone of the combustion of the fuel.

2. A new method of reducing the formation of nitrogen oxides in the furnace
In research laboratory of Heat power systems and Plants of Ulyanovsk State Technical University developed and patented a number of technical solutions aimed at suppressing the formation of oxides of nitrogen NOₓ. As the main way to reduce the combustion temperature of the fuel, it is proposed to introduce the blowdown boiler water into the combustion zone. Figure 2 shows a scheme, the difference of which is the simultaneous use of recirculation of combustion products and injection of purging water into the combustion zone [5].

![Figure 2](image_url)

According to the proposed technology, purging water enters in the flue gases recirculation duct before the boiler furnace. The required amount of purge water is controlled by means of a flow regulator.
installed in the purging pipeline. By the impulse from the temperature sensor located in the most heat-stressed part of the boiler furnace, the controller changes the volume of the injected moisture into the recirculation flue duct, thereby ensuring a change in the combustion temperature of the fuel to the specified values.

The organization of flue gas recirculation and the simultaneous introduction of moisture into the zone of combustion of the fuel in the proposed scheme can effectively reduce the combustion temperature of the fuel, decrease the amount of chemical underburn.

To determine the efficiency of the introduction of this technology and assess its feasibility, preliminary calculations have been made for a boiler type TGM-314P. The results of the calculations showed that the introduction of a part of the purge water into the flue gases recirculation duct at a purge water flow rate of 7 t/h reduces the temperature of the gases in the furnace by approximately 50°C.

The input of blowdown water into the combustion zone of the boiler can also be carried out directly into the furnace of the boiler without the organization of recirculation of the combustion products [6]. The scheme of this solution is shown in Figure 3. The volume of injected moisture is also regulated by the pulse from the temperature sensor installed in the zone with the highest combustion temperature of the fuel. This solution is the simplest in design and provides the necessary temperature reduction, and as a result prevents the formation of undesirable nitrogen oxides NOₓ.

![Figure 3. Scheme of a steam boiler with the introduction of purging water into the furnace: 1 – furnace, 2 – boiler drum, 3 – purging water pipeline, 4 – regulating organ, 5 – temperature controller, 6 – temperature sensor.](image)

To determine the effectiveness of reducing nitrogen oxide concentrations, the proposed technology compares (Table 1) there were calculated values of nitrogen oxide concentrations for gas combustion for two schemes: without introducing purging water into the furnace of the boiler and using the inlet of purge water according to RD 34.02.304-95 [7].

Preliminary was determined the value of the thermal load \( q_{l,g} \) of the radiation surface of the active combustion zone, MW/m², according to the formula

\[
q_{l,g} = \frac{Q_{ir}B_{r,2}}{2(x_T + b_T)Z_{lay}h_{lay} + 1.5x_Tb_T'},
\]

as well as the initial mass concentration of nitrogen oxides during combustion of gas \( C_{NO_x}^{in} \), mg/m³,

\[
C_{NO_x}^{in} = 613 (\xi_1 q_{l,g})^{0.88}K_m K_a \]

The values of the coefficient \( K_m \), taking into account the air temperature before the burners equal to 0.99 and the coefficient \( K_a \), taking into account the excess air in the furnace, equal to 1.35 are the same for the two compared circuits. At the same time, the values of the coefficient \( K_m \), which takes into account the supply of moisture to the combustion zone, are different.
Table 1. Calculation of the mass concentration of nitrogen oxides.

| Calculation formula | Value without purging water | Value with the introduction of purge water |
|---------------------|-----------------------------|------------------------------------------|
| Coefficient $K_m$, considering the supply of moisture $K_m = 1 - \alpha_m g_m$ | 1                           | 0.9725                                  |
| Estimated mass concentration of nitrogen oxides $C_{NO_x}$, mg/m$^3$ | $C_{NO_x} = C_{NO_x}^{in} K_{h,a} K_a K_v K_m K_N$ | 208                                     | 202.28                                  |

The data of the calculation carried out showed that the mass concentration of nitrogen oxides with the introduction of purging water decreased by about 6 mg/m$^3$. This means that the proposed technical solution can be practically used to reduce the combustion temperature of fuel and decrease emissions of nitrogen oxides into the environment.

Conclusions

- explored the mechanisms of formation of nitrogen oxides during fuel combustion, their types and properties, affecting the environment and the human body;
- proposed the technologies that allow to reduce the emission of NO$_x$ oxides with outgoing gases by introducing purging water into the flue gases recirculation duct or directly into the furnace of the boiler;
- the calculation of the effectiveness of solutions is made. Comparing of the boiler operation parameters in the mode without introducing purging water into the furnace and the mode using the inlet of the purge water showed a decrease in the mass concentration of nitrogen oxides in the flue gases by about 6 mg/m$^3$.

References

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