Atmospheric protection technologies for coal thermal power plants in eastern regions of Russia

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Abstract. Environmental problems of thermal power plants in the eastern regions of Russia are associated with emission of a significant amount of pollutants into the atmosphere. In recent years, documents have been adopted in Russia at the government level concerning the introduction of modern innovative technologies in all industries, including the energy sector. On July 1, 2018, a reference book of the best available technologies became operative. This reference book contains a list and analysis of the best available technologies for large coal-fired heat power plants, including atmospheric protection measures. For large thermal power plants, three pollutants are primarily considered: particulate matter, nitrogen oxides and sulfur dioxide. For each of them, the article discusses the best available technologies for reducing emissions into the atmosphere. The atmospheric protection technologies include technologies of the preliminary preparation of fossil fuel for combustion as well as technical purification systems of each pollutant. Sulphur dioxide is the main impurity of emission from coal-fired thermal power plants, and one of the attractive ways to reduce its emissions is the thermal preparation of coal before combustion. This technology has been experimentally tested at ESI SB RAS. This article discusses preliminary estimates and calculated emissions obtained.

1. Introduction

Thermal power plants have developed significantly in the energy sector especially in the eastern regions of Russia. Thus, 68\% of generating capacities in Russia are thermal power plants that operate in eastern regions of Russia, and more than 80\% use coal as fuel\cite{1}. The operation of coal-fired power plants influences all of the elements in the environment. However, the most significant influence is associated with significant emissions of pollutants into the atmosphere.

The main impurities from thermal power plants (TPP), which is reflected in the reports of energy enterprises and statistical publications, are particulate matter, sulfur and nitrogen oxides, volatile organic compounds, and carbon monoxide. Currently, some large energy enterprises report about greenhouse gas emissions, mainly, carbon dioxide. The analysis of the existing statistics of pollutant emissions into the atmosphere from large thermal power plants shows that out of 2-2.5 million tons of annual gross emissions in Russia, approximately 40-42\% are emissions of TPPs in the eastern regions. The predominance of sulfur dioxides characterize the structure of gross emissions in both entire Russia and eastern regions (table 1).

In general, to reduce the anthropogenic impact on the atmosphere, it is necessary to implement various environmental protection measures. For large thermal power plants, such measures have been largely developed.
Table 1. Structure of gross air emissions from thermal power plants in Russia and eastern regions, %

| Country, region | Particulate matter | Sulfur dioxides | Nitrogen oxides | Carbon monoxide |
|----------------|-------------------|----------------|----------------|----------------|
| Russia         | 28.0              | 46.0           | 23.0           | 3.0            |
| Eastern regions| 27.0              | 49.0           | 21.0           | 3.0            |

They include both rather simple preventive measures and sophisticated environmental protection technologies, such as:

- Pre-treatment and purification of fuels before combustion allows extracting some harmful components in special plants and factories, thereby, improving the quality of the original fuel.
- Technological measures to prevent the formation of harmful impurities in the fuel combustion process, including measures related to the constructive changes in fuel combustion devices, with the regulation of fuel combustion modes as well as the use of additives and agents in the fuel path to suppress the formation of pollutants.
- Cleaning flue gases from harmful impurities by purification devices suggests the installation of special cleaning systems after combustion of fuels. As a rule, these bulky installations require large territorial spaces and appropriate communications to allocate the by-products.
- Substitution of one fuel by a more environmentally friendly one during the combustion.
- Introduction of zero waste technologies, i.e. the involvement of products that pollute the environmental elements in the technological process (existing or new) or production.

2. Methods of investigation

The approaches to the choice of technologies that reduce and clean air emissions were developed depending on the emissions of pollutants. The main harmful impurities characteristic of combustion of fossil fuels at large power plants are as follows: water vapor, carbon (soot), shale ash, fuel oil ash of TPPs in terms of vanadium pentoxide, inorganic dust, suspended solids, sulfur dioxide, carbon monoxide, nitrogen oxides, benzo(a)pyrene as well as some heavy metals depending on the deposit.

Relying on the fact that the state reports and reports of energy enterprises provide information only on the emissions volumes of the main four components (particulate matters, carbon oxides, sulfur, and nitrogen), the choice of technologies is based on these harmful impurities.

The intensity and volume of emissions depend on many factors: the capacity and efficiency of the boiler units, the amount of fuel and their physical and chemical properties (ash content, sulfur content, humidity, calorific value, etc.), the type of the combustion device, and the purification degree of flue gases.

The methods for estimating the amount of emissions from large TPPs include Methods for determining the gross emissions of pollutants from thermal power plants, which were approved at the state level [2-4], as well as existing regulatory thermal calculation methods for steam boilers of power plants [5, 6].

The choice of technologies is associated with analytical studies assessing their advantages and disadvantages, production capacity in the selection of specific equipment, the quality characteristics of the captured harmful impurities as well as the cost of the technological devices themselves [7, 8].

3. Discussion of the transition to innovative technologies

To solve environmental problems in the energy sector, including those related to significant emissions into the atmosphere from large thermal power plants, in 2014, various regulations were adopted in Russia to introduce innovative technologies and transit to the best available technologies (BAT) [9, 10].
In general, BATs include only the technologies that provide the highest quality of the product, are economical and widely used in Russian and foreign enterprises. Concerning large energy enterprises, such technologies should include those with the least impact on the elements of the environment, taking into account economic and technic efficiency, as well as the period of implementation (short-term – from weeks to months, medium – up to one year, and long-term – more than one year) [11, 12].

To ensure and implement measures for the transition of large energy enterprises to BAT, an Information and technical reference book of the best available technologies has been developed: ITS 38-2017 "Fuel Combustion at large plants for energy production" [1] (approved by the Rosstandart order No. 2929 of December 22, 2017). It identifies the best available technologies for burning solid, liquid and gaseous fuels.

Atmospheric protection technologies of coal-fired heat power plants include technologies for unloading, storage, pre-treatment, and combustion of fuel as well as technical systems for reducing the emission of each ingredient [13].

Particulate matter emissions can be significantly reduced by using pre-combustion fuel purification: coal enrichment, energy technology coal processing and gasification of solid fuels. Such technologies can reduce humidity, ash and sulfur content, and increase the calorific value of fuels. Reduction of emissions of solid substances into the atmosphere is possible through technological measures taken in the process of fuel combustion. These include constructive and regime measures that improve fuel burnout and reduce heat losses of boiler plants by decreasing air intake volume, the additional lining of the boiler, etc. Constructive measures (creation and implementation of special furnace and burner devices) are considered more reliable, as they have a comparative constancy in time. Regime measures related to change and regulation of the combustion process may have different efficiency and variability in time.

The installation of ash-collecting devices is widely spread among the methods for reducing particulate matter emissions. To ensure the required emission standards for solid particles, it is necessary to clean the flue gases with an efficiency of 99-99.9%. Among the methods of purification from particulate matters, the most widespread are filtering technologies, gravitational separation (cyclones) and wetting (scrubbers) flue gases, table 2.

Table 2. Characteristics of the main best available technologies to reduce particulate matter emissions [1].

| Technology            | Efficiency, % | Specific capital expenditures, RUB/kW | Implementation time, months* |
|-----------------------|---------------|--------------------------------------|-------------------------------|
| Electrostatic precipitators | 99.5-99.9     | 1080 min 2900 max                    | 12 min 18 max                 |
| Emulgents             | 99.5          | 320 min 540 max                      | 10 min 16 max                 |
| Venturi scrubbers     | 98.5          | 290 min 470 max                      | 10 min 16 max                 |
| Hose filter           | 99.9          | 1700 min 2800 max                    | 12 min 18 max                 |

Note:* time of work on the boiler, excluding project and expert procedures

It should be noted that cleaning systems with venturi tubes are widely used, and 53% of the Russian thermal power plants are equipped with them. Expensive installations, for example, hose filters work only at two thermal power plants but are actively used abroad.

Atmospheric technologies of TPP to reduce gaseous emissions (sulfur and nitrogen oxides) are associated with both the reorganization of the coal combustion process and the installation of purification devices.

To reduce emissions of nitrogen oxides, methods for suppressing their formation are currently used. Table 3 shows various constructive and regime methods, which allow reducing the formation of nitrogen oxides in two-three times or more.
Table 3. Characteristics of some of the best available technologies to reduce nitrogen oxides [1].

| Technology                                              | Potential reduction % | Specific capital expenditures, RUB/kW | Implementation time, months* |
|---------------------------------------------------------|-----------------------|--------------------------------------|-----------------------------|
| Flue gas recirculation                                  | Up to 20              | 20-70                                | 0.5-3.0                     |
| Two-stage combustion                                    | Up to 45              | 70-140                               | 2.0-3.0                     |
| Low-toxic burners                                       | 30-40                 | 60-200                               | 2.0-4.0                     |
| Low-toxic burners and stepped air inlet                 |                       |                                      |                             |
| Low-toxic burners with two-stage combustion and flue gas recirculation | 44-73                 | 135-250                              | 1.5-2.5                     |
|                                                         |                       |                                      |                             |
|                                                         |                       | 50-78                                | 150-400                     | 2.0-6.0                     |

Note: * time of work on the boiler, excluding project and expert procedures

Currently, methods for cleaning flue gases from nitrogen oxides have been developed. They are divided into wet and dry, catalytic and non-catalytic, cyclic and non-regenerative ones. By physical and chemical features, they can be also divided into absorption, adsorption and catalytic oxidation. The most common plants are those with selective non-catalytic reduction technology, in Russia, there are three such plants at TPP with nitrogen oxides capture efficiency of up to 51% [1].

In general, there are various methods of flue gas purification, which can simultaneously reduce the emission of sulfur and nitrogen oxides with a high degree of extraction of the pollutant. These include:

- Cyclic method of activated coke gas purification.
- Electron beam processing method.
- Ammonia-ozone purification of flue gas.

These methods are not widely used in Russia due to their high cost. Currently, there are only a few experimental-test and pilot facilities. At the same time, the use of gas purification even at large power facilities leads to a rise in the production cost (electric and thermal energy), and according to estimates, capital expenditures in gas treatment devices can be from 25 to 35 % of the cost of all TPP equipment [14].

Methods for suppressing the formation of nitrogen oxides in the combustion process are recognized as the most effective and the best available technologies. They are largely applied at all coal-fired plants both in the eastern regions and the rest of Russia. Methods for purifying flue gases from nitrogen oxides are rather effective but expensive and not widely used.

As noted above, the main environmental problem of thermal power plants is a significant release of sulfur oxides. The emission of sulfur oxides can be reduced in the process of coal combustion when part of SO₂ is bound by ash in the furnace. The proportion of sulfur that can be bound in the furnace depends on the ash content in the fuel and the content of free alkali (calcium oxide, magnesium, etc.) in the fly ash as well as on the method of slag removal. For example, the efficiency of binding sulfur oxides in the combustion of Berezovsky coals may reach 20%.

Methods of chemical interaction between the pollutant and the reagent (absorption, adsorption and catalytic oxidation) are used to clean flue gases from sulfur dioxide. All methods of desulfurization can be divided into wet and dry. The wet method is based on the absorption of sulfur oxides by aqueous solutions or suspensions of various oxides and salts. The dry cleaning process has two stages: the absorption of sulfur oxides from flue gases by solid or liquid sorbents and the regeneration of the adsorbent (desorption of sulfur oxides). In industrial plants, liquid-phase processes dominate due to a large number of particulate matters in flue gases, which can clog adsorbents and catalysts during gas-phase (dry) cleaning.
There is no industrial implementation of technologies for purifying sulfur oxides at existing thermal power plants; therefore, it is proposed to use coal with low sulfur content as the main technology.

### 3.1. Thermal preparation of the fuel to the combustion

One of the promising directions can be the thermal preparation of fuel before its combustion by extracting harmful and polluting components from fuels. Thermal treatment of coal provides almost complete removal of fuel nitrogen and sulfur compounds, which can significantly reduce or eliminate the emissions of oxides from these substances into the atmosphere.

Experiments on thermal preparation of coal (on the example of Mugunsky coal) have been carried out in ESI SB RAS. The results have shown not only an increase in calorific value of fuel and reduction of the nitrogen and sulfur content but also a significant increase in the ash content. The calculation of the amount of emissions (under equal conditions of combustion in large boiler plants) per tonne of coal equivalent has indicated that the total emission for the three main ingredients of the heat-treated fuel (Mugunsky semi-coke) is 2.4 times higher (table 4).

| Fuel               | $W_i$, % | $A_d$, % | $S_{daf}$, % | $Q_{daf}$, MJ/kg | Emission, kg/t c.e. |
|--------------------|----------|----------|---------------|-------------------|---------------------|
| Mugunsky coal      | 21.6     | 5.6      | 0.6           | 16.6              | 78.2                |
| Mugunsky semi-coke | 1.4      | 17.2     | 0             | 20.7              | 232                 |

Consideration that all large power stations are equipped with ash treatment systems, the use of thermal preparation technology for coal will significantly reduce the gross emissions of TPPs.

### 4. Conclusion

The study has revealed the main environmental problems in the operation of large power plants, which are associated with anthropogenic impact on the atmosphere, especially, in the eastern regions of Russia.

An analysis of existing atmospheric protection technologies for thermal power plants, taking into account the best available technologies, has shown that technologies for reducing particulate matter emissions with a high purification degree of up to 99% were developed and have a wide industrial implementation.

Atmospheric protection technologies for thermal power plants to reduce gaseous emissions (sulfur and nitrogen oxides) are connected with environmental measures of technological and constructive nature. Gas-purification equipment, as a rule, is bulky, has complex physical and chemical processes and requires the installation of specific devices.

One of the promising directions may be the thermal preparation of fuel before its combustion, which will eliminate the emission of sulfur oxides. This is the most important for large energy facilities in the eastern regions of the country and can compete with expensive sulfur recovery facilities.

### Acknowledgments

The studies were carried out within the framework of the state task on the implementation of the basic project of ISEM SB RAS III.17.6.1. Reg. No. AAAA-A17-117030310445-9
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