Development of engineering and technical environmental measures for technogenic atmospheric pollution by thermal power facilities

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Abstract. Technological processes are considered at the objects of heat power engineering - combined heat and power plants. The principle of operation of heat power facilities is considered on the example of the Voronezh TPP-1. The equipment is considered, with the help of the rational use of which the required level of ecological safety of the technogenic object can be achieved. Taking into account the peculiarities of the processes carried out at Voronezh TPP-1, the most effective set of engineering, technical and environmental measures aimed at reducing the technogenic impact of the TPP on the city’s atmosphere is proposed. In developing recommendations on the use of effective environmental measures at the CGP, the works were considered.

1. Introduction

A significant number of works have been devoted to the issues of energy supply to consumers of various levels from sources of various profiles and purposes [1-30]. It is specifically necessary to emphasize the ecological orientation of a significant part of publications devoted to sources of energy production by the traditional and non-traditional method and alternative forms of its formation [5,7-9]. Two directions of publications dedicated to energy supply can be distinguished:

1. Improvement of the technological regulations for the operation of power plants based on hydrocarbon raw materials, providing modern methods for protecting the atmosphere, hydrosphere, lithosphere from the negative impact of energy facilities - thermal power plants [1,2,10-14].
2. Replacing hydrocarbon feedstocks with alternative energy sources of various forms, including hydrogen, here we can note the development of solid-phase hydride support systems, which are promising technologies for future generations [5,7-9].

The purpose of this article is the analysis and technological proposals for improving the technological regulations for the operation of cogeneration plants (CGP) using Voronezh city as an example.

Consider the history of the development of the Voronezh CGP -1. The year of commissioning is 1933. In October 25, 1933, the first powerful power station of the capital of the Black Earth Region, the Voronezh State District Power Station (VOSDPS), was launched. In 1959, VOSDPS received a new name - "Voronezh CGP - 1", which is located at street. Lebedeva, house number 2.
At the station, work is constantly underway to modernize and increase capacity. Station specialists use modern technology in their work. In the past few years, an automated process control information system has been introduced; two reverse osmosis water treatment plants began to operate. In the same period, the gas equipment of boilers was reconstructed using the «AMAKS» gas burner control system.

Today, CGP - 1 is a production unit of the Voronezh branch of PJSC “Quadra - Power Generation” and takes an active part in the investment program to upgrade generating capacities, which the company implements.

Voronezh CGP - 1 is glorious not only of its production achievements, but also of people - real professionals and labor dynasties, whose experience is passed down from generation to generation. Voronezh TPP-1 supplies Levoberezhniy with heat, as well as parts of the Leninsky and Zheleznodorozhny districts of Voronezh.

2. Principle of operation of CGP
The cogeneration plant (CGP) is a type of thermal power plant that produces electrical and thermal energy used for the operation of centralized heat supply systems. Figure 1 shows a schematic diagram of a CGP.

Today in Russia, most stations use natural gas as fuel. Voronezh CGP uses Stavropol gas. It enters the CGP through the pipeline. The fuel then goes to the boiler room. There are two types of boilers at the TPP: TP (pulverized coal) and BKZ.

Electric energy is produced in a generator located on the same shaft as the turbine. Generators can work both on air, and hydrogen cooling. When working on air cooling, the power is less and equal to 25 MW, on hydrogen it reaches 30 MW. Before being transferred to the electric network, the voltage is increased in the transformers in order to reduce the loss of electricity during transmission over distances. Another part of the spent steam is used for the heating of the city. The steam enters the network heaters and transfers thermal energy to the network water, which goes to hot-water boilers and heat points.

Gas is used as fuel at CGP -1. The reserve fuel (coal and fuel oil) is intended to ensure reliable and uninterrupted operation of the power plant during the cooling period, when restrictions on gas consumption may be introduced - the main type of fuel for CGP and boiler houses of JSC «Quadra». We will consider the operation of coal-fired CGP. The schematic diagram of the cogeneration plant is shown in figure 1.

In order to use purified feed and make-up water at the CGP, which is taken from the Voronezh reservoir, a chemical water treatment system (CWT) is installed, which includes clarifiers (1 stage of water preparation), mechanical filters (loaded with anthrocite), sodium-cation exchange filters (passes into two steps, loaded with ion-exchange resin), sand-mechanical filters (loaded with quartz sand), a water treatment plant using reverse osmosis (deep water desalination, membrane technology).

The desalination plant of the chemical workshop is designed to produce demineralized water for feeding power boilers. Source water is treated according to a two-stage desalination scheme. The capacity of the desalination plant is 400 m³ / h. A chemical laboratory is involved in water quality testing, analyzes and takes samples at various points in the boiler.

Delivery of coal raw materials is carried out using gondola cars. In winter, coal in gondola cars is thawed in defrosters with the help of heated air, after which the coal softens. Next, coal in gondola cars is moved to a dumping device-dump truck, where it rotates to a maximum angle of 180 ° relative to the longitudinal axis. Then the coal is discharged into the lower coal bin for raw coal. Further, coal is fed from the bunkers to the underground conveyor, vertical, and then through the inclined conveyor it enters the mill to the boiler room. Grinding of crushed coal is carried out in a drum mill.

The ball drum mill (BDM) has the form of a cylindrical drum with overall dimensions up to 1.5 to 4 meters wide and 2.5 to 12 meters long (Figure 2). In order to avoid wear, the BDM is internally covered with manganese steel plates. The plates act as armor and have a wavy contour. A layer of
asbestos is placed between the drums and the armor to suppress noise. The outer drum is covered with felt, performing the role of heat and sound insulation, and on top of the felt is a metal case.

Figure 1. Schematic diagram of the CGP:
1-steam boiler; 2-steam turbine; 3-generator; 4-capacitor; 5 condensate pump; 6-nutrient pump; 7-low pressure heater; 8-high pressure heater; 9-deaerator; 10-production steam consumer; 11-network water heater; 12-heat consumer; 13-network pump; 14-supply of chemically purified water to make up for losses of steam and condensate.

Figure 2. General view and section of a ball drum mill:
1 - a large pipe; 2 - pillow block bearing; 3 - mill drum with heat and sound insulation; 4 - outlet pipe; 5 - a big gear; 6 - gear; 7 - electric motor.

BDM is filled with balls with a diameter of 25 to 75 mm for 30% of the volume. When the drum rotates at a speed of 700 rpm, the balls move due to centrifugal force to the top of the drum, reach a certain height, then separate from the wall, fall back onto coal, which gradually begins to turn into powder from dynamic action. The grinding of coal occurs mainly under the influence of falling metal balls, partly due to abrasion from rolling balls. Next, the dust is fed to the burners of the boiler, where there are mill fans.

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Centrifugal mill fans FM-50/1000 are designed for pneumatic transportation of coal dust in dust preparation systems for solid fuel boilers, when grinding fuel with drum-ball mills. Fans create high pressure at relatively low capacity and are subject to intense abrasive wear of coal dust.
General information about the FM 50/1000 (Figure 3) is as follows. The fan has one-way suction. Rotary spiral housing. Radially ending blades. The number of blades is 10. The direction of rotation is right and left. Determined by suction side.
Mill fans pick up dust and cause fine particles to enter the boiler burners. The layout of the boiler is made in a U-shape. The boiler has a combustion chamber, which has an upward gas duct and a convection lowering shaft with two separated gas ducts. In the combustion chamber there are evaporative screens and burners placed in two rows. Upper - working burners, and lower - kindling.
The boiler unit is equipped with a pulverized coal furnace for burning coal with dry slag removal. The combustion chamber with a volume of Vt = 896 m³, shielded by 83 × 4 mm pipes. Convection superheater, two-stage, with heating surface H = 549 m². The tail surfaces of the heating are made according to a two-stage scheme. The economizer of the first and second steps is steel, coil, made of pipes with a total heating surface of H = 140 m². Steel air heater, tubular with heating surface H = 10560 м² (Figure 4).
The boiler is designed for the following steam parameters:

- rated steam capacity 170 t/yr;
- drum pressure 10 MPa;
- pressure behind the main steam valve 9.8 MPa;
- superheated steam temperature -503°C;
- feed water temperature 215°C.
- Boiler efficiency 92-93%

Electric energy is produced in a generator that is located on the same shaft as the turbine. The generator operates on air and hydrogen cooling. The power of the generator is 25 MW air-cooled and 30 MW hydrogen-powered. Before transmission to the electric network, the voltage is increased in transformers with a voltage of 110 kV in order to reduce the loss of electricity during transmission over distances.

**Figure 3.** FM mill fan -50/1000.

**Figure 4.** The scheme of the drum boiler TP-170: 1 - burner; 2 - combustion chamber; 3 - furnace screen; 4 - drum; 5 - lowering pipes; 6 - festoon; 7 - superheater; 8 - convection duct; 9 - economizer; 10 - tubular air heater; 11 - lower collectors of the furnace screens.

### 3. Steam gas installation

At Voronezh CGP -1, two combined-cycle power units are included:

- 4 gas turbines LM6000 PD Sprint, manufacturer General Electric.
- 4 waste heat boilers PK-95, manufacturer of JSC "Zio".
- 2 steam turbines PT-25 / 34-3,4 / 1, 3, 4, manufacturer JSC "KTZ".

The site for the placement of a complex of reverse cycle facilities is 200 m away from the main one and is a wasteland, free of buildings, without woody vegetation.

The site of the CCGT main building with the main and auxiliary buildings and structures is located on the site of the former open solid fuel warehouse and warehouse-type buildings that must be dismantled. The designed switchgear building is located in the western part of the Voronezh CGP -1 site, closer to the reservoir in the area of the existing workshop of the CEM, pumping station for the reverse water supply system for oil coolers, direct current installation buildings, etc.

Combined steam and gas installations operate in a clearly defined sequence of actions, taking into account the joint operation of gas turbines and steam turbine installations. To clean the gas turbine unit entering the air inlet of atmospheric air, a comprehensive air-cleaning device (CACD) is installed. It
consists of protective visors and cellular dehumidifiers, flat dehumidifier panels, coarse pre-filters, fine filters. CACD are used together with centrifugal, axial air compressors and gas turbines. The use of CACD as a part of the gas-turbine tract eliminates the erosive wear of the blade apparatus and contamination of the flow parts of compressors and turbines. CACD increases the reliability of high-performance GTE, reduces fuel and energy costs and increases the average operational efficiency of engines.

Figure 5 graphically demonstrates the principle of operation of a combined cycle plant. Figure 6 shows a general view of the LM6000 gas turbine.

In addition to equipping the heat and power plants with modern energy production technologies, we note a number of measures that contribute to the reduction of environmental stresses arising from the operation of thermal power plants. A whole range of publications is devoted to this direction; we note some of them \[5,7-14,20\].

**Figure 5.** The principle of operation of combined cycle equipment - combined cycle plant.

**Figure 6.** General view of the LM6000 - gas turbine: 1 - input rotary guide vanes; 2 - 5-stage low-pressure compressor; 3 - bypass air pipe; 4 - 14-stage high-pressure compressor; 5 - 2-stage high pressure turbine; 6 - 5-stage low pressure turbine; 7 - a combustion chamber; 8 - fuel collectors; 9 - auxiliary gear; 10 - drive flange.

4. **Measures to reduce emissions to atmosphere at CGP**

Emission reduction at the Voronezh TPP-1 is achieved by regime measures \[1-4, 6\]. Consider the activities \[1-2, 6, 10-14\], the implementation of which will help to reduce harmful technogenic emissions from the CGP into the surrounding atmosphere.

4.1. **CGP transition to two-stage fuel combustion.**

The essence of the method is that the combustion of gaseous products must be divided into two steps or stages. At the first stage, the air supply is significantly less than the amount required for the final combustion of the fuel. As for the second stage, the resulting incompletely burned combustible material from the first stage should completely burn out in the second stage. As a result of this sequence of the combustion process, the maximum flame temperature in the burner will decrease, and as a result, the rate of synthesis of combustion products, which are harmful substances emitted into the
atmosphere, will decrease. In accordance with such conditions of gas combustion, the formation of NO\textsubscript{X} will decrease by 30-50%.

Two-stage gas combustion can occur in various constructive ways. For this, a two-stage boiler unit with multi-row burners is most often used.

Two-stage combustion is a simple, inexpensive, and effective way to reduce nitric oxide production.

4.2. Reduced boiler workload.
It is a known fact that a decrease in the workload contributes to a decrease in heat transfer in the considered unit of area or volume, which leads to a decrease in the flame temperature and the formation of oxides from the effects of temperature. When the load decreases by 25% during gas combustion, then NO\textsubscript{X} emissions are reduced by 50%.

Under adverse weather conditions, they switch to a different mode of operation of the boiler. The main goal of the mode cards is to ensure reliable and economical operation of the boiler with minimal emissions of harmful substances (nitrogen oxides) into the atmosphere in the adjustment range of loads, which can be influenced by the operation mode of the furnace, the work is informed about this trend [3, 4, 6, 15, 20].

4.3. Redistribution of fuel in the burners.
Emission control is carried out by manual gas analyzers.

The gas analyzer is a special device with which quantitative and qualitative compositions of gas mixtures are measured. According to the principle of operation, gas analyzers can be manual and automatic.

In hand-held gas analyzers, absorption components are most often produced, which make it possible to absorb the chemical components of the gaseous medium using various reagents. Such hand-held gas analyzers are the most common. The work of a manual gas analyzer is carried out by sequentially performing the following steps: sampling a certain sample volume at a fixed atmospheric pressure, then extracting the necessary component from the sample using the selected known method, and finally measuring the volume of the remaining modified sample. Similarly, using the method described above, a multi-component analysis is performed. A manual gas analyzer allows you to get only information about the intermediate state of the process under study, and usually when it is applied, there is some delay for the case of a rapid assessment of the environmental situation.

5. Conclusion
For the development of the global economy, natural gas offers great opportunities. Fuel in the form of gas is the “cleanest” fossil fuel, because if it burns completely, then only nitrogen oxides are released from a number of toxic substances. In the event of incomplete combustion, carbon monoxide (CO) is formed, which is present in wastewater.

In the past few years, an automated process control information system has been introduced at Voronezh CGP-1; two reverse osmosis water treatment plants began to operate. In the same period, the gas equipment of boilers was reconstructed using the AMAKS gas burner control system. Emission reduction at the enterprise is achieved by regime measures.

Based on the problems of atmospheric pollution considered in this work by emissions of the Voronezh CGP-1, which uses natural gas as the main fuel, comprehensive measures have been proposed aimed at reducing the concentration of emissions in the surrounding environment in order to ensure the environmental safety of the industrial economy. These activities include engineering, technical and environmental measures.

When implementing a large-scale reconstruction project at CGP-1 in Voronezh using modern combined-cycle technology for the production of heat and electric energy, the final result can be achieved - improving the environmental situation in the city of Voronezh with a population of more than one million people due to a significant reduction in emissions of combustion products.
In conclusion, we note that technogenic production also has adverse effects on the urban environment due to excess noise levels [11-13]. Experimental studies of the steam generator and consideration of its environmental friendliness were considered in [1-4,6,12-15,23]. In developing recommendations on the use of effective environmental measures at the CGP, the works [1-4,6,16-20] were considered. The basis for solving modern engineering, technical and scientific problems is information technology [1-4,6,15,21-30]. The complex of the considered tasks for specific economic objects, taking into account dangerous natural factors based on modern information technologies [4,6,15,21-30] will contribute to improving the technosphere security.

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