Technogenic impact of the heat and power plant on the environment and the development of environmental engineering measures

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Abstract. The article studies the waste generated during the operation of the heat and power plant, an energy facility. The analysis of atmospheric pollution by emissions of the Voronezh HPP-1, which uses coal as the main fuel, was carried out. A comparison is made with a thermal power plant using gas as a fuel source. The maximum allowable emission standards for pollutants generated during the use of coal were established and the excess of the MPC value by various types of emissions was shown: dioxide and nitric oxide; fuel oil and NO2+SO2 ash; sulfurous anhydride and carbon monoxide; soot and coal ash. The size of the Sanitary Protection Zone of HPP-1 was determined. Measures aimed at reducing the negative environmental impact of energy facilities such as combined heat and power plants are proposed.

1. Introduction

An extensive number of publications [1-30] was devoted to the issues of the technogenic impact of heat and power plants (HPP) on the environment and the development of engineering and environmental protection measures, which is predetermined by the significance of this area.

A review of the literature shows the following main trends in the development of the dilemma: the need for energy supply - technogenic pollution of the atmosphere, hydrosphere, lithosphere:

1. Replacement of heat and power plants by hydroelectric power plants (HEPPs) and nuclear power plants (NPPs), which from an environmental perspective has prospects with the reasonable technical operation. However, the use of nuclear power plants has hidden potential threats with the slightest violation of the technological regulations, and this is a rather expensive method of generating energy, and therefore not all countries of the world can afford it [1-4]. However, only those countries that have hydrological resources can build HEPPs.

2. Replacement of hydrocarbon raw materials (coal, fuel oil, gas) by alternative sources; a significant advantage is the use of hydrogen as an energy source [5-7].

3. The transition of heat and power plants from an energy carrier - coal to natural gas. Coal burning produces, as it is known, soot and carbon monoxide (II), sulfur dioxide, nitrogen oxides, which are the main pollutants of the environment. Unlike coal, when burning natural gas, water and carbon monoxide (IV) are formed, which do not cause environmental stress.
4. Equipping HPPs with modern purification technologies: waste gases into the atmosphere, sewage into water basins and soil, as well as reducing the amount of aggressiveness of production waste.
5. The use of information technology for the effective management of production technological regulations and taking into account the influence of hazardous natural factors on the safe mode of operation of HPPs.

The aim of the work was a comparative analysis of the technogenic impact of HPP plants using coal and natural gas on the environment in terms of atmospheric emissions, for compliance with environmental standards, determining the sanitary protection zone of a facility and the development of environmental engineering measures.

The Voronezh HPP-1 is a cogeneration plant located in the city of Voronezh, which is part of JSC “Quadra”. It is located at 2, Lebedev ast., Voronezh. The main function of the HPP is the production of electricity and heat. The Voronezh HPP-1 is a large thermal power plant with an estimated electric capacity of 138 MW and an energy capacity of 1181 Gcal/h (Figure 1).

![Figure 1. Voronezh HPP-1.](image-url)

2. Description of the Voronezh HPP waste
The following wastes are characteristic of the Voronezh HPP:
1. Scum. Hazard class - 4. Scale formation - the oxidation of metals when heated in the presence of oxygen. The scum on the internal parts of the boiler reduces heat transfer and increases energy intensity. The increase in scum on the walls of the boiler significantly reduces its functional resources. Intense scum formation is most often observed when burning fuel oil.
2. Fuel fats (mazut ash) are created by periodically removing and depositing dust from a heated surface outside the boiler.
3. Oil sludge in tanks during cleaning. It is a heavy distillate liquid fuel (mazut) mixed with water.
4. The soil containing petroleum products is formed during the leakage of fuel oil when it is pumped into the tank and filled with sand.
5. The washing water of regenerative air heaters and convective heating surfaces of oil-fired boilers. When neutralizing, the wash water is treated with a solution of lime in the neutralizing tanks, after which it enters the discharge bowl.
6. Waste generated from clarifiers and Na-cation exchange filters:
   - carbonate sludge;
   - water containing mechanical impurities generated during the process of loosening and washing, mechanical clarifying filters;
   - water containing mechanical impurities generated during the loosening of sodium - cation exchange filters;
   - spent regeneration solutions formed in the process of restoring the exchange capacity of Na-cation exchange resin containing sodium chloride, calcium chloride and magnesium chloride;
   - water after washing Na-cation exchange filters containing sodium chloride.
7. Used oils, being a waste of hazard class 3, must be disposed of or processed.
8. Ash and sludge waste.

3. Analysis of the Voronezh HPP operation
Let us analyze the operation of the Voronezh HPP and find out what environmental standards will be respected. The purpose of standardization is to establish maximum permissible standards, for example, maximum permissible concentration (MPC).

In the laboratory of the Voronezh HPP-1, it was found that the amount of coal burned annually is 123,997 tons, the combustion of which produces 40 million tons of ash and sludge, which is 27.5% of fuel consumption. The ash content in the slag is 85.4%.

The supply of carbon fuel is carried out by special railways. Gondola cars are pushed into the unloading device, in which the coal is thrown into the lower bunker for raw coal. Then the coal is fed vertically from the bunker into the underground vertical conveyor and then fed through an inclined conveyor to the mill of the boiler shop.

Grinding of crushed coal is carried out in a drum mill. The temperature of the furnace reaches 1700°C. With these processes, deposits form on the boilers.

When burning coal fuel in boilers, pollutants are formed that are emitted into the atmosphere through chimneys, which affect air pollution. MPC of pollutants are given in table 1.

| Name of substance | Hazard class | MPC of the substance, mg/m³ |
|------------------|--------------|----------------------------|
|                  |              | Maximum one-time | Daily average |
| C₂₀H₁₂           | 1            | -                 | 0.01           |
| NO₂              | 2            | 0.085             | 0.04           |
| NO               | 3            | 0.4               | 0.06           |
| SO₂              | 3            | 0.05              | 0.5            |
| SO₃              | 3            | 0.3               | 0.1            |
| Industrial soot  | 3            | 0.15              | 0.5            |
| CO               | 4            | 5                 | 3              |

As a result, we set the maximum permissible emission standards for pollutants generated by using coal. Figures 2, 3, 4, 5 show the values of exceeding the maximum permissible concentrations (MPC) of various types of emissions.

The analysis shows a significant excess of pollutant concentrations created by emissions from the production of the HPP-1. The analysis shows significant excesses in the concentration of pollutants created by emissions from the main production of the HPP-1. Thus, the coal-fired HPP-1 is characterized by emissions of nitrogen dioxide, sulfurous anhydride, NO₂+SO₂, which are 3-4 times higher compared to the gas-fired HPP-2. Also, emissions of nitric oxide and carbon monoxide from the HPP-1 twice exceed emissions from the HPP-2. And the main indicators are soot and coal ash emissions, which are completely absent in the gas HPP.

4. Sanitary protective area
The production area of the HPP-1 is 967674 m². The sanitary protection zone (SPZ) for the production unit of the HPP-1 was agreed by the Center for State Sanitary and Epidemiological Supervision of the city of Voronezh on the basis of the "Project for the organization of the sanitary protection zone of the HPP-1", developed by PC "Gasproject Engineering".

Based on SanPiN 2.2.1/2.1.1.1200-03, the size of the SPZ was established and agreed upon (Figure 6). This figure shows the location of the equipment for the subsidiary farm of the HPP-1 of the branch of JSC “Quadra - Power Generation” - “Voronezh Regional Generation”.

The territory of the enterprise has a main fence made of reinforced concrete slabs, partially equipped with barbed wire on top. During the operation of the HPP-1, Donetsk coal of the ASh type is
used. When it is burned in boilers, pollutants are formed that are released into the atmosphere through chimneys, which have a significant effect on air pollution.

As a result of fuel combustion, harmful and dangerous combustion products are formed. Reducing emissions of pollutants into the atmosphere from the production process of the HPP-1 is due to the implementation of measures to protect atmospheric air.

The mode of operation of the boiler, where the fuel is burned, is carried out according to the regime map, which indicates the optimal parameters for the operation of the boiler, as well as values for harmful emissions [2-5]. It is a working document of the boiler and must be executed, Figure 7.

5. Methods for reducing harmful emissions into the atmosphere
Let us consider methods to reduce harmful emissions into the atmosphere.

Method 1 - the use of a smoke exhauster D-18x2. A double-suction centrifugal exhaust fan D 18x2 is designed to remove flue gases from coal boiler furnaces with a residual dust content of flue gases of not more than 2 g/m³. The main principle of the device is forced air injection. Rotation of the impeller causes air to rush to the center of the structure. Having reached it, the air is thrown off by the walls of the exhauster and enters the furnace of domestic boilers. Gradual exhaustion takes place there, which ensures the influx of a new portion of air masses and, thereby, a continuous circulation is created. The blades in the device provide a vortex air movement directed towards the rotation of the powerful fan rotor. This creates a constant and continuous cycle - the influx of pure oxygen into the furnace of the unit, which produces heat and at the same time efficiently extracts the products of combustion of various fuels from it, including gas and solid components.

Method 2 - the use of a plate electrostatic precipitator. The design of the two-chamber electrostatic precipitator consists of the following set of elements: an inlet and outlet ducts, vertically located
chamber, precipitating and corona-forming electrodes, frame, dust collector, valve and distribution grill. Precipitation electrodes in this electric filter consist of a thin steel plate of the thickness of 3 mm. Electrodes are strung between the upper and lower frame. Both frames connected by rods are suspended from an external porcelain insulator. The electrodes are shaken manually using a special oscillating device. In the electrostatic precipitator, the electrodes are suspended at the top of the chamber. Dust adheres to the plates in the electrodes, during dynamic influences adhering dust is poured and falls down the chamber, then it is mechanically removed from the device. An electric filter can, at a gas speed of 0.7 meters per second, reduce the dust content in it to 0.2 grams per cubic meter.

Figure 6. Scheme of the Sanitary Protection Zone of the HPP-1.

Method 3 - the use of fuel additives. Environmental effects are as follows:
1. Reducing the share of CO in emissions;
2. Reducing NO\(_x\) emissions by reducing excess air;
3. Reducing carbon emissions by modifying the chemical constituents of dust;
4. Reducing the amount of thermal radiation by reducing the airflow in the boiler;
5. A significant reduction in the formation of SO\(_3\);
6. Reducing the share of SO\(_2\) and CO\(_2\) in emissions due to a decrease in fuel consumption in case of increasing the efficiency of the boiler.

Thus, the fuel additive can be considered as an effective inexpensive technology that not only optimizes the operation of equipment but also reduces production and operating costs, being an actual rational choice for solving environmental problems.

Method 4 - gas purification using a Venturi scrubber, considered in many works. One of the modifications of the Venturi scrubber and the features of its operation are considered in detail in [8].

The use of modern organizational and technical measures discussed above, as well as information and analytical methods considered, for example, in [3, 7, 9, 10], in the work of the Voronezh HPP-1, is aimed at reducing emissions, protecting the environment and the population.

6. Atmosphere protection activities
The emission of pollutants into the atmosphere generated during the production process at the HPP-1 is reduced through the implementation of comprehensive air-protection measures in recent years: the
introduction of modern dust collectors in coal boilers with cleaning up to 94.78%, which ultimately leads to a reduction in emissions of coal ash from boilers when optimizing their combustion modes, when replacing burners in coal boilers at the HPP-1, which ultimately leads to a reduction in emissions of nitric oxide.

The use of the smoke exhauster D-18x2 (Figure 8). A double-suction centrifugal exhaust fan D 18x2 is designed to remove flue gases from boiler furnaces on coal with a residual dust content of flue gases of not more than 2 g/m³.

\[ \text{Figure 7. Mode map of the boiler TP-170.} \quad \text{Figure 8. Smoke exhauster D 18x2.} \]

The main principle of the device is forced air injection. Rotation of the impeller causes air to rush to the center of the structure. Having reached it, the air is thrown off by the walls of the smoke exhauster and enters the furnace of domestic boilers. Gradual exhaustion takes place there, which ensures the influx of a new portion of air masses and, thereby, a continuous circulation is created. The blades in the device provide a vortex air movement directed towards the rotation of the powerful fan rotor. This creates a constant and continuous cycle - the influx of pure oxygen into the furnace of the unit, which produces heat and at the same time efficiently extracts the products of combustion of various fuels from it, including gas and solid components.

The advantages of using scrubbers are a high level of purity in the area of centrifugal forces, a low value of hydraulic resistance, simplicity of the design solution and high economic efficiency. Scrubber installation costs 200-300 thousand rubles.

7. Conclusion

Organizational and technical measures used at the Voronezh HPP-1 are mainly aimed at reducing emissions and protecting the atmosphere. Specialists of the HPP-1 strive to keep up to date and apply modern technologies in their work.

In conclusion, we note that technogenic production also has adverse effects on the urban environment due to excess noise levels [11]. Experimental studies of a steam generator and consideration of its environmental friendliness were considered in [12-15]. When developing recommendations on the use of effective environmental measures at the HPP, the works [16-18,20] were considered. The basis for solving modern engineering, technical and scientific problems is information technology [19,21-30]. The complex of the considered tasks for specific economic objects using modern information technologies will contribute to improving the technosphere safety of functioning.
References

[1] Crabtree G W Dresselhaus M S and Buchan M V 2004 The hydrogen economy *Physics Today* 57(12) 39–44

[2] Ohi J 2005 Hydrogen energy cycle: An overview *J Mater Res* 20(12) 3180–7

[3] Zvyagintseva A V 2008 Interaction peculiarities of hydrogen and Ni-B galvanic alloys NATO Science for Peace and Security Series C: Environmental Security vol PartF 2 437–442

[4] Zvyagintseva A V 2006 The effect of boron on the hydrogenation of nickel films *International scientific journal Alternative Energy and Ecology* 5(37) 85–86

[5] Zvyagintseva A V 2015 The ability of materials based on nickel of the nanoscale range to hydrogen storage *International scientific journal Alternative Energy and Ecology* 21(185) 150–155

[6] Graetz J 2009 New approaches to hydrogen storage *Chem. Soc. Rev* 38 73–82

[7] Zvyagintseva A V 2017 Hybrid functional materials forming metal structures with optimal defectiveness for storing hydrogen in hydride form *International scientific journal Alternative Energy and Ecology* 16-18(228-230) 89–103

[8] Zvyagintseva A V and Shalimov Y N 2014 On the stability of defects in the structure of electrochemical coatings *Surface Engineering and Applied Electrochemistry* 50(6) 466–477

[9] Zvyagintseva A V Shalimov Y N 2011 Increase of solubility of hydrogen in electrolytic alloys Ni-B NATO Science for Peace and Security Series C: Environmental Security 2 519–528

[10] Zvyagintseva A V Shalimov Y N 2008 Energetics of metal hydrides formation in electrochemical systems NATO Science for Peace and Security Series C: Environmental Security PartF2 pp 175–182

[11] Asminin V F, Druzhinina E V, Sazonova S A and Osmolovsky D S 2019 Development and application of a portable lightweight sound suppression panel to reduce noise at permanent and temporary workplaces in the manufacturing and repair workshops *Akustika* 34 18–21

[12] Zvyagintseva A V, Sazonova S A and Kulnueva V V 2019 Modeling of fugitive emissions of dust and gases into the atmosphere in open pits mining and processing plants, and improving measures to improve working conditions *Proceedings of the Seventh International Environmental Congress* (Samara-Togliatti, Ninth International Scientific-Technical Conference "ELPIT 2019") Edition ELPIT. Printed in Publishing House of Samara Scientific Centre pp 212–226

[13] Zvyagintseva A V Shalimov Y N 2008 Mechanisms Of Metal Hydrides Formation In The Presence Of Boron Compounds NATO Science for Peace and Security Series C: 4Environmental Security PartF2 pp 443–448

[14] Bianco V Rosa De M Scarpa F and Tagliafico L A 2016 Analysis of Energy Demand in Residential Buildings for Different Climates by Means of Dynamic Simulation *International Journal of Ambient Energy* 37(2) 108–120

[15] Zvyagintseva A V, Sazonova S A and Kulnueva V V 2019 Measures to improve working conditions and reduce dust and gas emissions in the quarries of the mining and processing plant IOP Conference Series: Materials Science and Engineering (Vladivostok, International science and technology conference "FarEastCon-2019") IOP Publishing in press

[16] Zvyagintseva A V and Kravtsova Y G 2007 The problem of hydrogen permeation into the boron doped electrodedeposited nickel films NATO Science for Peace and Security Series A: Chemistry and Biology pp 661–664

[17] Zvyagintseva A V Shalimov Y N 2011 Laws of diffusion of hydrogen in electrolytic alloys on the basis of nickel NATO Science for Peace and Security Series C: Environmental Security 2 529–534

[18] YAkovlev D V and Zvyagintseva A V 2012 Construction of an interbranch integrated geographic information system of the Voronezh region *Izvestia of the Samara Scientific Center of the Russian Academy of Sciences* 1-3 923–930
[19] Arzhanykh Yu P, Dolzhenkova V V and Zvyagintseva A V 2014 Prediction of hydrological situation during floorage at water bodies of the Voronezh region using geographical information systems Heliogeophysical studies 9 89–98

[20] Zvyagintseva A V 2019 Mathematical model of hydrogen permeability of metals with impurities traps in the presence of internal stresses of various physical nature International scientific journal Alternative Energy and Ecology 19-21 (303-305) 29–44

[21] Dolzhenkova V V and Zvyagintseva A V 2015 Prospects the use of GIS Floodmap technologies for predicting the risk of flooding on water objects of the Voronezh region Bulletin of the Samara Scientific Center of the Russian Academy of Sciences 17(6) 70–81

[22] Avdyushina A E and Zvyagintseva A V 2014 Analysis of statistics of aircraft collisions with birds for 2002-2012 and modern means of providing ornithological safety of flights Heliogeophysical studies 9 65–77

[23] Zvyagintseva A V and Kravtsova Y G 2007 Hydrogen permeation and nickel films structure correlation NATO Science for Peace and Security Series A: Chemistry and Biology vol 2007 pp 665–669

[24] Zhu L H Tan and J Yu 2013 Analysis on optimal heat exchanger size of thermoelectric cooler for electronic cooling applications Energy Conversion and Management 76 685–690

[25] Zvyagintseva A V Tenkaeva A S Mozgovoy N V 2015 The effect of the composition of natural water on the corrosion resistance of steel X40 trunk pipelines Bulletin of the Samara Scientific Center of the Russian Academy of Sciences 17(5) 276–282

[26] Pearson M R and C E Lents 2016 Dimensionless Optimization of Thermoelectric Cooler Performance When Integrated Within a Thermal Resistance Network Journal of Heat Transfer 138(8) 081301–081301-11

[27] Zvyagintseva A V 2017 Hydrogen permeability of nanostructured materials based on nickel, synthesized by electrochemical method Proceedings of the 2017 IEEE 7th International Conference on Nanomaterials: Applications and Properties "NAP 2017" IEEE Catalog Number: CFP17F65-ART part 2 02NTF41-1-02NTF41-5

[28] Dunikov D Borzenko V and Malyschenko S 2012 Influence of impurities on hydrogen absorption in a metal hydride reactor International Journal of Hydrogen Energy 37 13843–13848

[29] Tereshchenko M A and Brain N In 2009 Experimental investigation of the steam generator on the basis of pulsating combustion and the assessment of its sustainability Teploenergetika 6 69–72

[30] Sazonova S A, Nikolenko S D and Osipov A A 2020 Simulation of a Transport Standby for Ensuring Safe Heat Supply Systems Operation IOP Conference Series: Materials Science and Engineering (Vladivostok, International science and technology conference "FarEastCon-2019") IOP Publishing 753 052004