

Comprehensive assessment of the anthropogenic impact of the «Aitas-Energo» enterprise on ambient air quality in East Kazakhstan

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Abstract. This article presents the results of identifying the main sources of anthropogenic environmental impact and assessing their effects on atmospheric air at «Aitas-Energo» enterprise, located in the settlement of Kasym Kaysenov, East Kazakhstan Region. The purpose of the study is to inventory organized and unorganized emission sources within the enterprise area, determine their quantitative and qualitative characteristics, and analyze the efficiency of the gas-cleaning systems. The research materials included emission source inventory data, design and technological documentation, industrial environmental monitoring reports, and technical specifications of the equipment. The methodological framework comprised calculation–analytical, inventory-based, and comparative analysis methods. Emission volumes were determined by calculation in accordance with the methodologies currently in force in the Republic of Kazakhstan.

The study identified 17 emission sources affecting atmospheric air at the enterprise, most of which are associated with boiler units, the coal storage facility, the ash and slag dump, repair workshops, and water supply systems. It was found that particulate matter and gaseous compounds account for a significant proportion of the pollutants released into the atmosphere. Analysis of the gas-cleaning equipment showed that the efficiency of particulate capture by battery cyclones corresponds to the design performance indicators.

The obtained results demonstrate the importance of continuous monitoring of atmospheric air quality within the enterprise area, strengthening measures aimed at reducing unorganized emissions, and improving the environmental management system. The research findings may serve as a scientific basis for planning environmental protection measures at the local level.

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Keywords: anthropogenic impact; atmospheric air; emission sources; environmental monitoring; boiler plant; gas-cleaning equipment; industrial pollution.

1. Introduction

The anthropogenic impact of energy enterprises on atmospheric air remains one of the key environmental challenges in contemporary

industrial regions. The use of solid fuels contributes to the formation of significant amounts of dust and gaseous emissions, including nitrogen oxides, sulfur dioxide, carbon monoxide, and particulate matter, which adversely affect ecosystem conditions and public health. This situation highlights the importance of conducting systematic environmental monitoring and scientifically substantiated assessments of emission loads.

For East Kazakhstan, which is characterized by a high concentration of energy and industrial facilities, assessing the impact of stationary sources of atmospheric air pollution is of particular importance. The operation of «Aitas-Energo» enterprise, which provides heat supply to settlements and industrial enterprises, is accompanied by the formation of local emission sources. The main contribution to the environmental load comes from emissions generated by boiler installations, the coal storage area, and associated facilities, which necessitates a comprehensive analysis.

The purpose of this study is to conduct a comprehensive assessment of the anthropogenic impact of «Aitas-Energo» enterprise on atmospheric air, to inventory emission sources, and to determine the efficiency of the existing gas-cleaning systems. The results obtained are intended to provide a scientific basis for improving industrial environmental monitoring and enhancing the level of environmental safety in the region.

To supply hot water to the nearby settlement of Kasym Kaisenov and to Ust-Kamenogorsk Poultry Farm, an industrial boiler plant located in the settlement of Kasym Kaysenov and operated under trust management by «Aitas-Energo» enterprise has been installed in the area.

The main activities of the enterprise include the production, transmission, distribution, and supply of thermal energy; water supply through main pipelines and distribution networks; wastewater disposal and treatment; technical maintenance of heating, water supply, and sewerage systems; repair of boilers, pressure vessels, and pipelines operating under pressure; as well as the sale and processing of slag. Such economic activities cause significant environmental impacts and result in the formation of a carbon footprint (Kabaeva, 2024).

The site of «Aitas-Energo» enterprise is bordered on all sides by the administrative and industrial facilities of Ust-Kamenogorsk Poultry Farm.

The nearest residential area is located to the northeast at a distance of 873 m from the outermost emission source.

No forests, agricultural lands, recreational areas, or health resorts are located in the immediate vicinity of the enterprise site (Kabaeva, 2024).

A schematic overview map showing the sources of pollutant emissions into the atmosphere is presented in Figure 1.



Figure 1. Overview schematic map of the facility indicating pollutant emission sources

The situational schematic map of the area where the facility is located is shown in Figure 2.



Figure 2. Situational schematic map of the area where the facility is located

The main activities of the enterprise include the production, transmission, distribution, and supply of thermal energy; water supply through main pipelines and distribution networks; wastewater collection and treatment; technical maintenance of heating, water supply, and sewerage systems; repair of boilers, pressure vessels, and pipelines operating under pressure; as well as the sale and processing of slag.

The enterprise operates 365 days per year on a continuous 24-hour basis.

The facilities of «Aitas-Energo» enterprise include a boiler plant, a coal storage area, an ash and slag disposal site, a heat network maintenance and service unit, a water supply and sewerage department, and a motor transport unit.

The boiler plant provides thermal energy and hot water to the settlement of Kasym Kaysenov and to the industrial and domestic buildings of Ust-Kamenogorsk Poultry Farm, and also supplies steam for industrial needs. The plant is equipped with five steam boilers.

The boiler plant operates on hard coal from the Karazhyra deposit (run-of-mine coal of grade «D») and additionally burns oil-contaminated cleaning rags as auxiliary fuel. The annual coal consumption amounts to 45.000 t, while the consumption of oil-contaminated rags is 1.0 t per year. Up to three boiler units may operate simultaneously.

Within the industrial site, an open coal storage area and an open ash and slag disposal site are located adjacent to the boiler plant.

The open coal storage area covers 2.400 m². Coal is delivered by road transport.

Removal of slag and ash from all boilers is carried out using a wet method. Slag and ash are conveyed through the slag removal system to collecting hoppers, from which, as they accumulate, they are transported by vehicles either for disposal or for temporary storage at the ash and slag disposal site, followed by transfer to construction organizations.

The ash and slag disposal site is open on all four sides and occupies an area of 4.493 ha. Its base consists of clays and loams that do not exhibit subsidence or swelling properties.

Personnel responsible for the maintenance and repair of heat networks service inter-site heat pipelines using mobile electric welding units and gas metal-cutting equipment. The workshop is equipped with metal-processing machines.

The Water Supply and Sewerage Department operates an integrated water supply system that provides water for industrial, domestic, and fire-fighting needs of the poultry farm and the facilities of the settlement of Kasym Kaysenov. Water supply sources include seven artesian wells (one of which is currently conserved) located in the settlement of Akhmirovo, from which water pipelines are laid.

Water is supplied via two parallel pipelines, each with a diameter of 200 mm, to two reservoirs, from which it is pumped by second-lift pumps to a third-lift pumping station. Subsequently, water is pumped to a fourth-lift pumping station and then delivered through the distribution network to the poultry farm and the settlement.

Disinfection is carried out on the enterprise premises using liquid chlorine at a LONII-100 unit. Liquid chlorine is delivered to the storage facility in sealed cylinders with a capacity of 25 kg. Dosing is performed through special valves based on sensor readings.

The motor transport unit is responsible for the operation and maintenance of the enterprise's vehicle fleet. The vehicles of «Aitas-Energo» enterprise are housed in garages leased from UKPF JSC (Lease Agreement No. 199-22 dated 30 December 2022).

The plan-schematic diagram showing the sources in the area where the facility is located is presented in Figure 3.

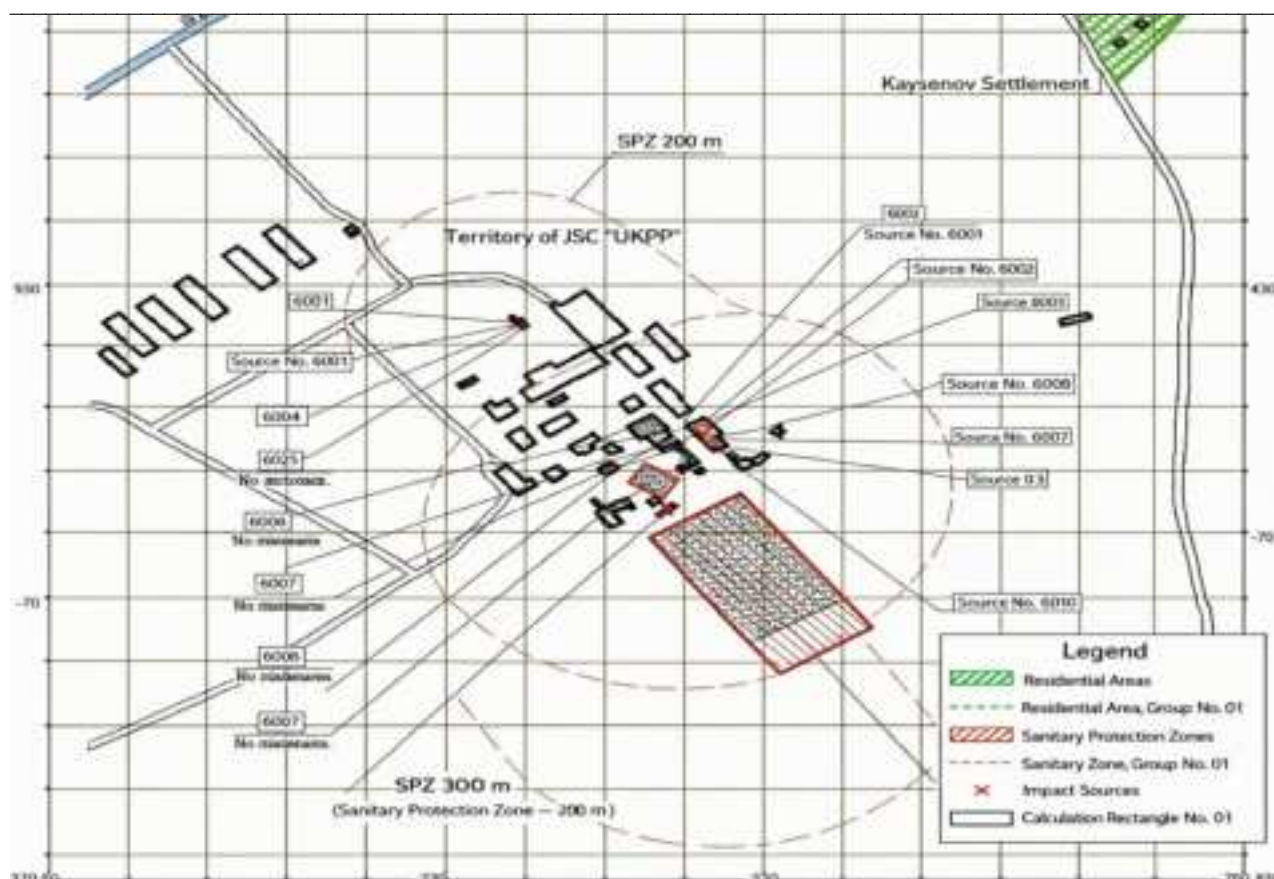


Figure 3. Plan-schematic diagram of the area where the facility is located, showing the sources

Emission Sources

Coal storage area:

Emission source 6001 – coal storage area.

Boiler plant:

Emission source 0001 – heat generation unit;

Emission source 0008 – new smokestack;

Emission sources 0003 and 0005 – repair works;

Emission source 6008 – instrumentation and control (I&C) workshop.

Ash and slag disposal site:

Emission source 6002 – ash and slag disposal site.

Heat network repair and maintenance unit:

Emission sources 6003, 6004, and 0006 – mechanical (locksmith) workshop;

Emission source 6009 – workshop.

Water Supply and Sewerage Department:

Emission source 0004 – chlorination room;

Emission sources 0007 and 6010 – welding station room;

Emission sources 6007 and 6005 – mechanical (locksmith) workshop.

Motor transport unit:

Emission source 6006 – motor vehicles with internal combustion engines.

Sanitary Protection Zones (SPZ):

SPZ for the boiler plant – 200 m.

SPZ for the ash and slag disposal site – 300 m.

2. Materials and methods

The research materials included inventory data on pollutant emission sources of «Aitas-Energo» enterprise, design and technological documentation, industrial environmental monitoring reports, as well as operational characteristics of the main and auxiliary equipment.

The object of the study comprises organized and fugitive sources of atmospheric pollutant emissions located within the industrial site of the enterprise in the settlement of Kasym Kaysenov, East Kazakhstan Region.

The methodological framework of the study was based on inventory, calculation-analytical, and comparative analysis methods for assessing anthropogenic impacts on atmospheric air.

The following methods were applied in the course of the study: analysis of technological flow diagrams and environmental documentation of the enterprise; inventory of pollutant emission sources; calculation of quantitative and qualitative emission characteristics; analytical assessment of the efficiency of gas-cleaning facilities; and cartographic analysis of the spatial distribution of sanitary protection zones and emission sources.

Pollutant emissions were determined using calculation methods in accordance with the methodological documents currently in force in the Republic of Kazakhstan. The following documents were used in the calculations: Methodology for Calculating Atmospheric Pollutant Emissions from Construction Materials Manufacturing Enterprises (Appendix No. 11 to Order No. 100-p dated 18 April 2008); Methodology for Calculating Atmospheric Pollutant Emissions from Welding Operations (regulatory guidance document 211.2.02.03-2004); Methodology for Calculating Atmospheric Pollutant Emissions from the Application of Paint and Coating Materials (regulatory guidance document 211.2.02.05-2004); Methodology for Calculating Pollutant Emissions from Motor Transport Enterprises (Section 3 of Appendix No. 3 to Order No. 100-p dated 18 April 2008); Collection of Methodologies for Calculating Atmospheric Emissions of Harmful Substances from Various Industries (Almaty: KazEKOEKSP, 1996, paragraph 2); and Methodology for Calculating Emission Standards for Fugitive Sources (Appendix No. 8 to Order No. 221-p dated 12 June 2014). Quantitative emission indicators were calculated for both the rated operating load and the actual maximum load of the equipment.

Primary data included annual fuel consumption, quantities of raw and auxiliary materials, technical specifications of boiler units, parameters of welding and repair equipment, and characteristics of smokestacks and gas-duct systems.

When performing the calculations, non-uniform annual operating regimes of emission sources, seasonal variations in heat load, cyclic patterns of technological processes, and scheduled equipment shutdowns were taken into account.

Gas flow parameters (volumetric flow rate, temperature, and emission composition) were determined based on equipment passport data, design specifications, and materials from industrial environmental monitoring.

The operational efficiency of dust collection units was assessed using the results of instrumental measurements conducted by an accredited laboratory, with a comparative analysis of design and actual purification performance indicators.

To assess the spatial relationship between emission sources, sanitary protection zones, and residential areas, overview and situational schematic maps were used.

3. Results

According to the inventory data, a total of 17 pollutant emission sources were identified at the enterprise, including 7 organized and 10 fugitive sources, of which 2 are non-stationary. In this context, the existing issues arising during coal transportation and storage can be classified as follows: contamination of areas adjacent to main transport routes with coal dust during the transportation of raw materials in open rail wagons; pollution of working areas in the vicinity of established coal stockpiles; and dispersion of fine dust particles beyond the storage area as a result of wind erosion, leading to environmental impacts on adjacent territories (Sikarev et al., 2020; Belyaev et al., 2017).

The facilities of «Aitas-Energo» enterprise that serve as sources of harmful atmospheric emissions include the coal storage area, the boiler plant, the ash and slag disposal site, heat network repair and maintenance units, the water supply and sewerage department, and the motor transport unit.

These facilities release pollutants into the environment, as noted by various authors in their studies (Lebedeva, 2010; Yazikov, 2003; Kolesnikov, 2023).

Coal storage facility. Coal with an annual volume of 45.000 tonnes is delivered by road transport to an open storage area covering 2.400 m². Stockpile formation and coal handling operations are carried out using a bulldozer. As a result of these activities, nitrogen dioxide, nitrogen oxides, carbon (soot), sulfur dioxide, carbon monoxide, kerosene vapors, and suspended particulate matter are emitted into the atmosphere. The emission source is unorganized (source No. 6001) (Molotilov et al., 2005; Cherechukin et al., 2016).

Boiler plant. The boiler plant provides thermal energy and hot water to the settlement of Kasym Kaysenov and to the industrial and domestic facilities of JSC «Ust-Kamenogorsk Poultry Farm» and also supplies steam for production needs to the industrial buildings of JSC «Ust-Kamenogorsk Poultry Farm».

Emissions are discharged into the atmosphere through a chimney with a diameter of 3.5 m and a height of 45 m (serving boilers Nos. 2, 3, and 4), as well as through a chimney with a diameter of 1.2 m and a height of 35 m (serving boilers Nos. 5 and 6). The emitted pollutants include nitrogen dioxide, nitrogen oxides, sulfur dioxide, carbon monoxide, and inorganic dust containing 20–70 % silicon dioxide. The emission sources are organized (source No. 0001 and source No. 0008).

Solid-fuel boiler installations, particularly those utilizing coal, are among the most significant stationary sources of greenhouse gas emissions and atmospheric pollutants. According to the review conducted by Tong et al. (2023), coal-fired boilers represent not only a major source of carbon dioxide (CO₂) emissions but also one of the primary anthropogenic sources of heavy metals formed during coal combustion and subsequently released into the environment through flue gases and ash–slag residues. The authors emphasize that the operation of coal-fired boilers is associated with the formation of a complex environmental burden encompassing both gaseous emissions and chemically hazardous solid waste.

Studies by Bhatt et al. (2023) indicate that industrial boilers are characterized by high emission factors and make a substantial contribution to the overall carbon footprint of energy and industrial systems. This is particularly relevant for boilers supplying heat and steam to municipal and industrial facilities, as such systems combine large fuel consumption volumes with continuous operating regimes. In heat supply systems, the contribution of boiler plants to the formation of the carbon footprint is considered one of the key determining factors. As demonstrated in the systematic review by Malcher et al. (2025), the heat supply sector accounts for a substantial share of global CO₂ emissions, while fossil fuel–based boiler installations are identified as priority targets for the development of decarbonization strategies and the reduction of carbon footprints.

According to the analytical review by Squires et al. (2016), the production of thermal energy based on the combustion of coal and other fossil fuels is characterized by a high specific carbon footprint, which necessitates mandatory consideration of emissions during the environmental assessment of heat supply facilities and in the development of environmental protection measures.

In addition, Şeneren et al. (2023) show that reducing the carbon footprint of heat supply systems is achievable through modernization of heat sources, implementation of heat recovery technologies, and improvements in the energy efficiency of boiler installations. This confirms that a comprehensive assessment of boiler emissions and energy performance constitutes the basis for developing measures aimed at reducing environmental loads.

Thus, the boiler plant supplying thermal energy and steam to the settlement of Kasym Kaysenov and the industrial facilities of JSC «Ust-Kamenogorsk Poultry Farm» operating with an annual coal consumption of 45.000 tonnes can be objectively classified as an environmentally significant facility. Its operation may be accompanied by the formation of a substantial carbon footprint and emissions

of air pollutants, thereby justifying the need for carbon footprint assessment, emission analysis, and the development of measures to mitigate adverse environmental impacts.

Maintenance and repair works. During maintenance and repair, operations at the boiler house, portable electric welding units, gas-cutting equipment, two drilling machines, and one grinding machine are used. The painting of technological equipment is performed manually.

The annual consumption of materials is as follows: MR-3 electrodes – 1.100 kg/year; TsL-11 – 30 kg/year; T-590 – 110 kg/year; propane – 600 kg/year; PF-115 enamel – 260 kg/year.

From the grinding machine, suspended particulate matter and abrasive dust are emitted into the atmosphere through a duct with a diameter of 0.5 m and a height of 1.5 m. Emissions from the remaining equipment are discharged through a duct with a diameter of 0.7 m and a height of 15 m and include iron oxide, manganese and its compounds, chromium, nitrogen dioxide, carbon monoxide, gaseous fluorine compounds, poorly soluble inorganic fluorides, xylene, white spirit, suspended particulate matter, and inorganic dust containing 20–70 % silicon dioxide. The emission sources are organized (source No. 0005 and source No. 0003).

Maintenance activities at the boiler plant, including electric arc welding, gas metal cutting, drilling and grinding operations, as well as manual painting of technological equipment, constitute energy-intensive and environmentally significant technological processes. Contemporary studies indicate that such activities generate not only direct emissions of pollutants but also an indirect carbon footprint associated with the consumption of electricity, fuels, and consumable materials.

Studies by Mehrifar et al. (2019), Riccelli et al. (2020), and Abdullahi et al. (2020) demonstrate that welding, painting, and surface treatment processes are among the operations with a high carbon footprint due to the combined effects of electricity consumption, fuel combustion, use of electrodes and coating materials, and the generation of aerosol and gaseous emissions. The authors emphasize that welding, cutting, and painting operations make a significant contribution to CO₂-equivalent emissions and pollutant releases within equipment maintenance and repair systems.

The study by Wu et al. (2025) shows that mechanical operations (drilling, grinding, and metal processing) are accompanied by persistent carbon emissions related to electricity consumption by machine tools, as well as the generation of suspended particles and metal dust. The authors substantiate the need to explicitly account for such processes when calculating the carbon footprint of industrial facilities, as even auxiliary production operations exert a measurable influence on total emissions.

According to Liu et al. (2024), technological chains that include cutting, welding, and painting operations are characterized by a complex environmental impact involving the formation of metal oxides, nitrogen oxides, carbon monoxide, volatile organic compounds, and particulate matter. The authors stress the necessity of integrating these processes into carbon footprint assessment frameworks and developing emission reduction measures, since they often represent underestimated sources of anthropogenic environmental pressure.

Thus, maintenance activities at the boiler plant associated with the use of electric welding and gas cutting equipment, machine tools, and coating materials are scientifically justified as additional sources contributing to carbon footprint formation and atmospheric air pollution. The generation of suspended particulates, metal aerosols, nitrogen oxides, carbon monoxide, and volatile organic compounds corresponds to the emission profiles described in contemporary studies of energy-intensive industrial processes (Wu et al., 2025; Liu et al., 2024), thereby confirming the necessity of considering these activities in the environmental assessment of boiler plant operations.

Instrumentation and Control (I&C) workshop. The Instrumentation and Control (I&C) workshop is located on the second floor of the boiler plant building. The workshop is equipped with grinding and drilling machines. As a result of these operations, suspended particulate matter and abrasive dust are released into the atmosphere. The emission source is unorganized (source No. 6008).

Ash and slag dump. The ash and slag dump is open on all four sides and occupies an area of 44.930 m². The annual volume of deposited ash and slag waste amounts to 11.182 tonnes. Formation and leveling of the ash and slag dump are carried out using a bulldozer. Because of these activities,

inorganic dust containing 20–70 % silicon dioxide is released into the atmosphere. The emission source is unorganized (source No. 6002).

Heat network maintenance and service personnel. The heat network maintenance and service personnel perform electric welding operations on inter-site heat pipelines (annual consumption of MR-3 electrodes – 200 kg/year), as well as gas metal cutting operations (annual propane consumption – 340 kg/year). In the mechanical workshop, grinding, drilling, and electric welding operations are carried out (annual consumption of MR-3 electrodes – 200 kg/year), and additional grinding operations are also performed.

The electric welding station in the mechanical workshop is equipped with a local exhaust hood and a duct with a cross-section of 0.3×0.2 m and a height of 3 m.

As a result of these activities, iron oxide, manganese and its compounds, nitrogen dioxide, carbon monoxide, gaseous fluorine compounds, suspended particulate matter, and abrasive dust are emitted into the atmosphere.

The emission sources include organized sources (source No. 0006) and unorganized sources (sources No. 6003, 6004, and 6009).

The operation of the I&C workshop, the activities of the maintenance personnel, and the use of the ash and slag dump are classified as technological processes contributing to both localized atmospheric air pollution and the formation of an additional carbon footprint of the enterprise. Contemporary studies indicate that mechanical processing, welding, gas cutting, and waste handling operations are energy-intensive processes that make a measurable contribution to greenhouse gas emissions through the consumption of electricity, fuels, and consumables, as well as through the generation of aerosol and dust emissions. Studies by Wu et al. (2025) and Stavropoulos et al. (2022) confirm that operations such as drilling, grinding, and polishing must be explicitly considered when modeling the carbon footprint of industrial facilities, as they lead to indirect CO₂ emissions and particulate matter formation. Research by Sarkar et al. (2022) and Zhou et al. (2025) demonstrates that welding and gas cutting processes are accompanied by emissions of metal aerosols, nitrogen oxides, carbon monoxide, and fluorine compounds, while simultaneously contributing to the carbon footprint through energy consumption and the use of electrodes and gases. The operation of the ash and slag dump, associated with the mechanical handling and storage of waste using machinery, also contributes to indirect CO₂ emissions and secondary dust generation (Stavropoulos et al., 2022).

Thus, the I&C workshop, maintenance units, and the ash and slag dump can be scientifically justified as sources contributing to the enterprise's carbon footprint and should be explicitly included in comprehensive environmental and climate impact assessments.

Water Supply and Sewerage Department. The enterprise operates an integrated water supply system that provides industrial, domestic, and fire-fighting water for the poultry farm and facilities in the Kasym Kaysenov settlement. The department includes a chlorination unit, a section for repair works on water supply networks, a welding station room, and a mechanical (fitter's) workshop.

Chlorination unit. Water disinfection is carried out using liquid chlorine in a LONII-100 unit. Liquid chlorine is delivered to the storage facility in hermetically sealed cylinders in an annual amount of 125 kg. During cylinder replacement, chlorine may be released into the atmosphere through the ventilation system via a duct with a diameter of 0.5 m and a height of 8 m. The emission source is organized (source No. 0004).

Repair works on water supply and sewerage networks. Repair works are carried out using a SAG welding unit (annual consumption of MR-3 electrodes – 270 kg/year) and gas cutting equipment (annual propane consumption – 200 kg/year). Painting works are performed manually using PF-115 enamel (100 kg/year). As a result of these activities, the facility releases iron oxide, manganese and its inorganic compounds, nitrogen dioxide, carbon monoxide, gaseous fluorine compounds, xylene, and white spirit into the atmosphere. The emission source is unorganized (source No. 6005).

The welding station room is equipped with an electric welding unit (annual consumption of MR-3 electrodes – 250 kg/year) and a grinding machine. The welding unit is fitted with a local exhaust hood and a duct with a cross-section of 0.15×0.15 m and a height of 1.5 m. These operations

release iron oxide, manganese and its compounds, gaseous fluorine compounds, suspended particulate matter, and abrasive dust into the atmosphere. The emission sources include an organized source (source No. 0007) and an unorganized source (source No. 6010).

The mechanical (fitter's) workshop is equipped with drilling and grinding machines. As a result of these operations, suspended particulate matter and abrasive dust are released into the atmosphere. The emission source is unorganized (source No. 6007).

Contemporary scientific studies indicate that the operation of water supply and wastewater systems contributes not only to localized atmospheric air pollution but also to the formation of the overall carbon footprint of an enterprise through energy consumption, the use of chemical reagents, and maintenance activities (Friedrich et al., 2009; Gui et al., 2024).

In the chlorination unit, drinking water disinfection is carried out using liquid chlorine. Chlorine is stored in hermetically sealed cylinders, and during cylinder replacement, there is a potential risk of chlorine release into the atmosphere through the ventilation system. The scientific literature emphasizes that water chlorination processes require mandatory environmental control, as storage, cylinder replacement, and ventilation operations may be accompanied by the release of toxic gases and the formation of environmental risks (Demir et al., 2024; Khalid et al., 2025).

Life cycle assessment results demonstrate that water disinfection systems contribute to the carbon footprint of water supply complexes through energy consumption and the production of chemical reagents (Demir et al., 2024).

Repair works on water supply and sewerage networks involve electric welding, gas cutting, and painting operations. During these processes, iron oxides, manganese and its compounds, nitrogen dioxide, carbon monoxide, fluorine compounds, as well as volatile organic compounds (xylene and white spirit), are released into the atmosphere. Studies indicate that welding and gas cutting are energy-intensive operations that generate not only direct emissions of pollutants but also contribute to the carbon footprint through electricity and fuel consumption (Sarkar et al., 2022; Zhou et al., 2025).

In the welding station and the mechanical (fitter's) workshop, mechanical metal processing operations (drilling, grinding, and polishing) are carried out. These activities are accompanied by the generation of suspended particulate matter and abrasive dust. According to Stavropoulos et al. (2022; Wu et al., 2025), such operations make a measurable contribution to the carbon footprint of industrial systems due to equipment energy consumption and particulate matter formation and therefore must be explicitly considered in environmental assessments.

The operation of the vehicle fleet department also indirectly contributes to the formation of the enterprise's carbon footprint. Studies indicate that transport services and the use of auxiliary equipment increase total CO₂ emissions through fuel combustion and energy consumption associated with supporting infrastructure (Friedrich et al., 2009; Gui et al., 2024).

Thus, the activities of the water supply and sewerage department, including the chlorination unit, engineering network repair works, welding and mechanical sections, as well as the vehicle fleet, constitute sources of the enterprise's integrated environmental and climate impacts. Contemporary scientific evidence confirms that these processes must be explicitly considered in the preparation of Environmental Impact Assessment (EIA) materials, as well as in the calculation of the enterprise's carbon footprint and the assessment of environmental risks.

Brief Description of Gas Cleaning Units, Aggregated Analysis of Their Technical Condition, and Operating Efficiency.

The boiler plant is equipped with five steam boilers, and the operating efficiency of the dust collection system is verified annually. The results of the efficiency inspections conducted in 2022 are as follows:

- DKVR-20/13 boiler No. 2 – efficiency: 83.28 %;
- DKVR-20/13 boiler No. 3 – efficiency: 83.81 %;
- DKVR-20/13 boiler No. 4 – efficiency: 84.57 %;
- KE-25/14 boiler No. 5 – efficiency: 85.56 %;

- KE-25/14 boiler No. 6 – efficiency: 85.0 % (according to passport data).

Each boiler is equipped with a BC-2-7×(5+3) battery cyclone.

Battery cyclones are dust collection units consisting of 56 cyclone elements arranged in parallel and combined into a single casing with common gas inlet and outlet systems.

Each cyclone element consists of a casing, a tangential swirl inlet device, and an outlet pipe. Flue gases exiting the boiler enter the cyclone element casing through the swirl device, where, under the action of centrifugal forces, ash particles are forced toward the inner surface of the cyclone, move downward along a spiral trajectory, and are discharged into the collection hopper.

The cleaned flue gases are conveyed through the outlet pipes to the clean gas chamber and subsequently to the chimney.

The cyclone elements are made of solid cast iron, have a diameter of 254 mm, and are equipped with «Rozetka»-type guide vanes with an inclination angle of up to 25°. The cyclone is divided into two sections operating in parallel, which can be isolated by means of slide gates (dampers). Safety valves are installed on the covers of each section to prevent damage to the cyclone in the event of explosions or pressure waves that may occur during the cleaning of explosive dust–gas mixtures.

The casing and hopper of the BC-2-7×(5+3) battery cyclone are fabricated by welding from plate steel. The welded joints of the battery cyclone casing ensure the gas-tightness of the entire unit, as shown in Figure 4.

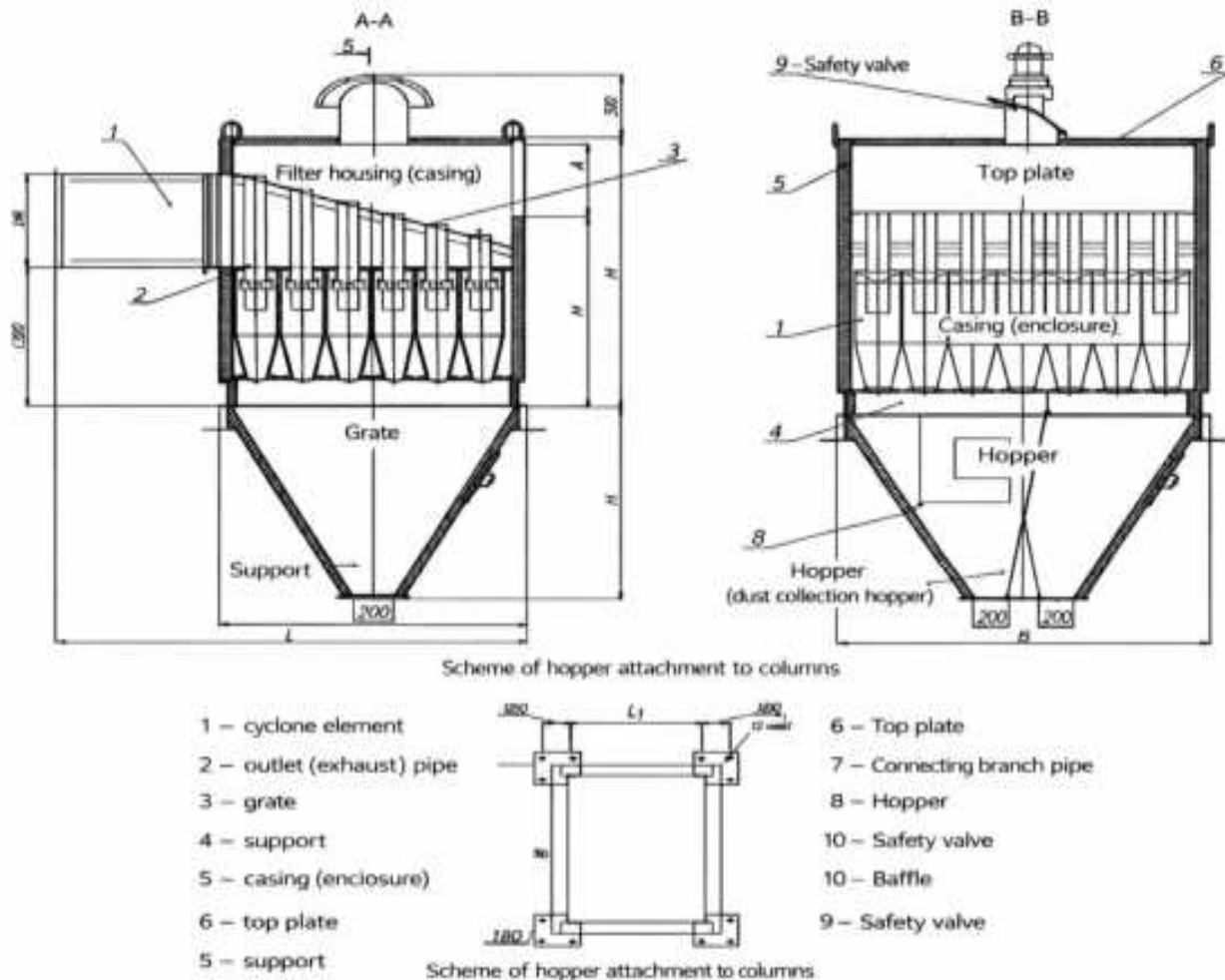


Figure 4. The auxiliary equipment of the boiler installations includes a «Battery Cyclone BC-2-7×(5+3),» consisting of the following components: 1 – cyclone element; 2 – outlet (exhaust) pipe; 3 – grate; 4 – support; 5 – casing (enclosure); 6 – top plate; 7 – connecting branch pipe; 8 – hopper; 9 – safety valve; 10 – baffle

The dust-laden gas enters the sections of the BC-2-7×(5+3) battery cyclone as a uniformly distributed total flow across the inlet cross-section. From this flow, the gas is directed into the individual cyclone elements, where, under the action of the swirl device blades, it begins to rotate. Due to inertial forces, solid ash and dust particles continue their direct motion, are pressed against the casing of the cyclone element, and then move downward together with the gas flow along the conical section of the casing.

As a result of the spiral vortex motion, a low-pressure zone is formed in the central part of the cyclone element. Consequently, in the lower part of the cone, the gas flow changes its direction, rises upward along the central axis of the cyclone element casing, and is directed to the outlet pipe. The ash and dust particles settle into the collection hopper, from which they are subsequently removed, as shown in Figure 4.

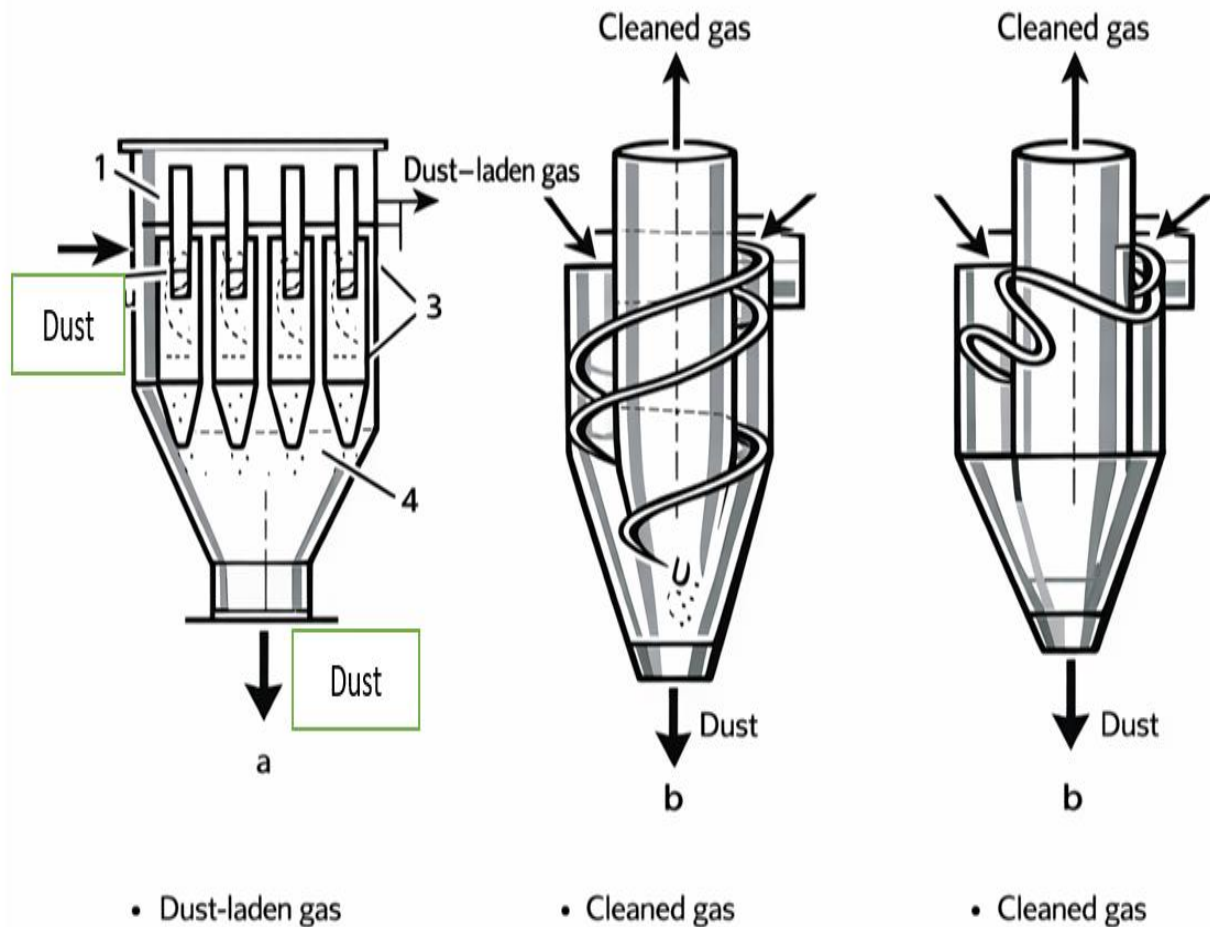


Figure 5. Operating schematic of the «Battery Cyclone BC-2-7×(5+3)» auxiliary equipment of the boiler installations

After passing through the battery cyclones, the cleaned gas is conveyed by induced-draft fans to a chimney with a diameter of 3.5 m and a height of 45 m (serving boilers Nos. 2, 3, and 4), and to a chimney with a diameter of 1.2 m and a height of 35 m (serving boilers Nos. 5 and 6).

The efficiency verification of the dust collection units was carried out in 2022 by the accredited organization IL «NPO «VK-ECO» enterprise (accreditation certificate No. KZ.T.07.0222 dated 24 January 2019).

Based on a comparison of the average operational and design collection efficiencies, it was concluded that the dust collection systems of the boiler plant operate effectively.

A brief description of the gas cleaning units at the enterprise is presented in Figure 5.

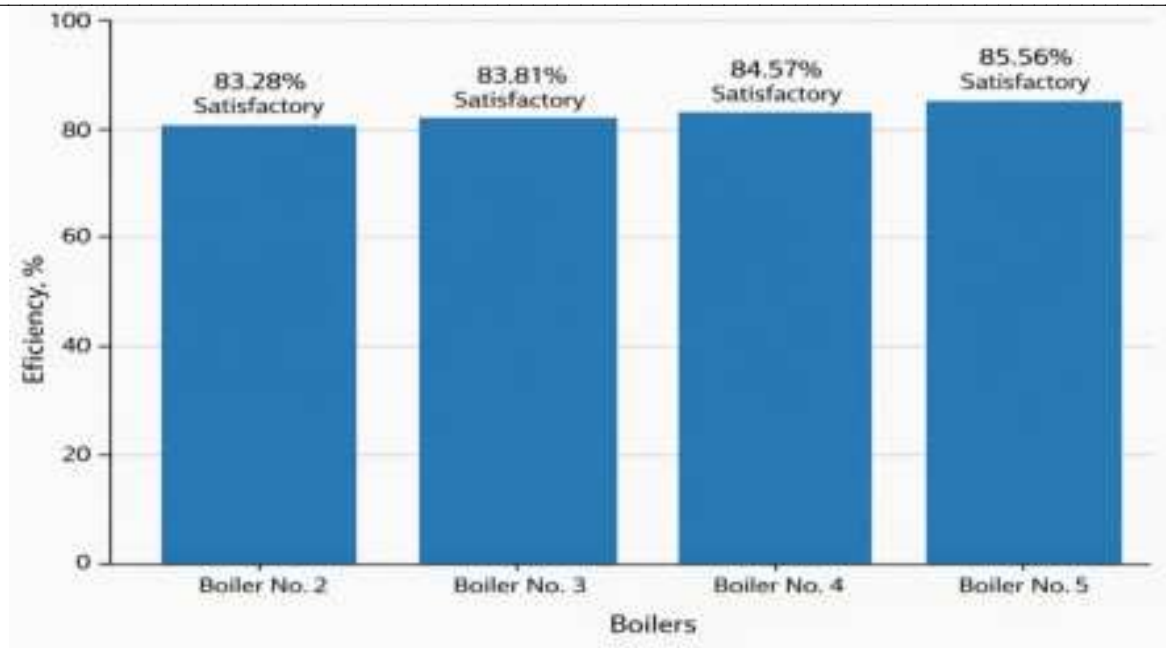


Figure 5. Efficiency (η) and technical condition of the BC units by boiler

Flue Gas Cleaning Methods. The conducted analysis indicates that the activities of «Aitas-Energo» enterprise constitute one of the significant stationary sources of anthropogenic environmental impact within the area where the enterprise is located. The main contribution to the formation of the environmental load arises from emissions generated by the boiler units, the open coal storage facility, the ash and slag dump, and the repair and mechanical sections. The emission profile, including suspended particulate matter, nitrogen oxides, sulfur dioxide, and carbon monoxide, corresponds to trends typical of industrially developed regions of Central Kazakhstan, where high values of the atmospheric pollution index and exceedances of maximum permissible concentrations of pollutants are recorded. This indicates the need to strengthen industrial environmental monitoring, modernize gas cleaning equipment, and implement integrated environmental protection measures at the enterprise (Beisenova et al., 2023).

At large industrial enterprises, the main devices used for flue gas cleaning from ash, dust, and non-adhesive solid particles include cyclones, scrubbers, electrostatic precipitators, and fabric (baghouse) filters. The method and type of gas cleaning equipment are determined and selected at the design stage of an energy facility as part of the overall project development.

In 1976, the standard boiler plant design envisaged the use of BC-2-7×(5+3) battery cyclones as dry (mechanical) dust collection devices. For their installation, calculations were performed regarding the boiler design and equipment layout.

Increasing the efficiency (η) of flue gas cleaning from the boilers would require a complete reconstruction of all boiler equipment and the boiler house building, as this would entail deviations from the standard boiler design. «Aitas-Energo» enterprise acts as the trust manager of the engineering infrastructure facilities of the Ulan District Akimat and does not have the financial capacity or resources to carry out reconstruction and modernization of the boiler plant. Moreover, reconstruction of the boiler equipment would lead to an increase in utility tariffs for the population, as the enterprise is a natural monopoly entity subordinate to the Department for Regulation of Natural Monopolies of the East Kazakhstan Region.

Within the framework of the enterprise's Environmental Protection Action Plan, it is planned to replace BC-2-7×(5+3) cyclones with new units in the event of equipment wear.

Under current conditions, boiler installations remain among the most widespread stationary sources of anthropogenic impact on the atmospheric air of settlements. According to data reported by a number of researchers, the combustion of solid fuels results in the emission of major pollutants such

as ash dust, sulfur oxides, nitrogen oxides, and carbon oxides, which adversely affect air quality and public health (Seinfeld et al., 2016; Vallero et al., 2014).

Studies by both domestic and international authors emphasize that small and medium-sized boiler plants operating in settlements and urban areas, especially under conditions of dense residential development and unfavorable meteorological conditions, contribute to the formation of localized pollution hotspots (Izrael, 2005). In this context, the efficiency of gas cleaning systems plays a critical role.

The most commonly used devices for the removal of ash and particulate matter in boiler installations are mechanical dust collectors, primarily cyclones and battery cyclones. Research by Cooper et al. (2011), Hoffmann et al. (2008), and Straus (1975) demonstrates that battery cyclones ensure stable removal of coarse and medium-sized particles from flue gases and are widely applied in energy and municipal facilities.

A number of studies are devoted to the analysis of the operational characteristics of cyclone separators and the assessment of their performance under real operating conditions. It is noted that the actual collection efficiency depends not only on the design of the cyclone but also on the operating regimes of the boilers, the particle size distribution of the ash, and the technical condition of the equipment (Wang et al., 2020; Perry et al., 2008).

In addition, contemporary research in the field of environmental assessment of energy facilities emphasizes the necessity of comparing the design and operational performance of gas cleaning units within the framework of industrial environmental monitoring (European Commission, 2017). Such an approach makes it possible to objectively assess the contribution of boiler plants to anthropogenic environmental loads and to substantiate decisions on whether existing gas cleaning systems should be modernized or retained.

Within the territory of Kazakhstan, the issue of emissions from boiler installations is particularly acute due to the widespread use of coal fuel and the deterioration of infrastructure. Studies by Kazakhstani researchers, along with data from state environmental monitoring services, indicate a significant contribution of boiler plants to atmospheric air pollution in settlements, thereby underscoring the need for localized investigations of anthropogenic impact sources.

Prospects for Enterprise Development. During the period 2023–2025, an increase in heat energy production volumes and the commissioning of new enterprise capacities, potentially accompanied by higher atmospheric pollutant emissions, may occur in connection with the development prospects of the Kasym Kaysenov settlement and the expansion of production capacities of JSC «Ust-Kamenogorsk Poultry Farm».

Description of Emergency and Accidental (Burst) Emissions

The enterprise has no emergency or accidental (burst) emissions of atmospheric pollutants. The technological processes implemented at the enterprise exclude the possibility of accidental or burst releases of pollutants into the atmosphere. Emergency situations at the enterprise may arise only as a result of adverse natural events (e.g., earthquakes, storms, etc.).

Field investigations are not required.

4. Discussion

The list of atmospheric pollutants was determined during the inventory of emission sources. During operation of the new chimney, a total of 16 pollutant emission sources will be present, including 7 organized and 9 fugitive sources, excluding the motor vehicle emission source (Kabaeva, 2024).

Under current conditions (2023), a total of 19 pollutants are emitted into the atmosphere in the amount of 1448.1809 t/year, including particulate matter – 479.2741 t/year and gaseous and liquid substances – 968.9068 t/year. Excluding vehicular sources, during operation of the new chimney, 17 pollutants are emitted into the atmospheric air in the amount of 1447.6794 t/year, including particulate matter – 479.2436 t/year and gaseous and liquid substances – 968.4358 t/year.

In 2024, total atmospheric emissions amount to 1448.1809 t/year for 19 pollutants (particulate matter – 479.2741 t/year; gaseous and liquid substances – 968.9068 t/year). Excluding vehicular sources, emissions during operation of the new chimney comprise 17 pollutants totaling 1447.6794 t/year (particulate matter – 479.2436 t/year; gaseous and liquid substances – 968.4358 t/year).

In 2025, total emissions remain at 1448.1809 t/year for 19 pollutants (particulate matter – 479.2741 t/year; gaseous and liquid substances – 968.9068 t/year). Excluding vehicular sources, emissions during operation of the new chimney amount to 1447.6794 t/year for 17 pollutants (particulate matter – 479.2436 t/year; gaseous and liquid substances – 968.4358 t/year) as presented in Table 1.

Table 1. Summary table of atmospheric pollutant emission volumes for the period 2023–2025

Year	Number of pollutants	Total emissions of all pollutants, t/year	Solid pollutants, t/year	Gaseous and liquid pollutants, t/year	Excluding motor vehicle emissions number of pollutants	Total emissions of all pollutants, t/year	Solid pollutants, t/year	Gaseous and liquid pollutants, t/year
2023	19	1448.1809	479.2741	968.9068	17	1447.6794	479.2436	968.4358
2024	19	1448.1809	479.2741	968.9068	17	1447.6794	479.2436	968.4358
2025	19	1448.1809	479.2741	968.9068	17	1447.6794	479.2436	968.4358

5. Conclusion

As a result of the conducted study, the main sources of anthropogenic impact on atmospheric air at «Aitas-Energo» enterprise, located in the Kasym Kaysenov settlement, were identified, and their quantitative and qualitative characteristics were comprehensively assessed. According to the emission inventory data, a total of 17 emission sources were registered within the enterprise area, including 7 organized and 10 unorganized sources. The principal pollution sources were identified as the boiler units, the coal storage facility, the ash and slag dump, repair workshops, the water supply and sewerage department, and the vehicle fleet department.

The structure of atmospheric emissions indicates the predominance of particulate matter (ash, inorganic dust, abrasive particles) and gaseous compounds (sulfur dioxide, nitrogen oxides, carbon monoxide, etc.). According to the calculated data, the atmospheric load generated by the enterprise is stable in nature and is mainly associated with the process of heat energy production.

Analysis of the gas cleaning systems demonstrated that the battery cyclones operate in accordance with their design efficiency and retain a significant proportion of particulate matter emitted from boiler sources. At the same time, the presence of unorganized emission sources, as well as the open storage of coal and ash–slag waste, increases the risk of localized atmospheric air pollution.

The study results highlight the necessity of continuous monitoring of atmospheric air quality within the enterprise area, strengthening technological and organizational measures aimed at reducing unorganized emissions, and implementing phased modernization of gas cleaning equipment along with improvements to the environmental management system. The obtained data may serve as a scientific basis for planning environmental protection measures and enhancing environmental safety within the territory of the Kasym Kaysenov settlement.

6. Supplementary Materials: No supplementary material.

7. Author Contributions

Conceptualization – Zh.K., A.A.; methodology – A.A.; software – S.A.; formal analysis – S.A., A.O., B.S.; Investigation – A.A.; resources – A.A.; data curation – Zh.K.; writing - original draft preparation - Zh.K.; writing-review and editing - Zh.K.; visualization - S.A.; supervision - Zh.K.; project administration - Zh.K. All authors have read and agreed to the published version of the manuscript.

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Шығыс Қазақстандағы «Aitas-Energo» кәсіпорнының атмосфералық ауа сапасына антропогендік әсерін кешенді бағалау

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Аңдатпа. Бұл мақалада Шығыс Қазақстан облысы Қасым Қайсенов кентінде орналасқан «Aitas-Energo» кәсіпорнының қоршаған ортаға антропогендік әсер ететін негізгі көздерін анықтау және олардың атмосфералық ауаға тигізетін ықпалын бағалау нәтижелері берілген. Зерттеудің мақсаты – кәсіпорын аумағындағы ұйымдастырылған және ұйымдастырылмаған шығарындылар көздерін түгендеу, олардың сандық және сапалық сипаттамаларын анықтау, сондай-ақ газтазарту жүйелерінің тиімділігін талдау. Зерттеу материалдары ретінде шығарындылар көздерін түгендеу деректері, жобалық-технологиялық құжаттама, өндірістік экологиялық бақылау есептері және жабдықтардың техникалық сипаттамалары пайдаланылды. Әдістемелік негіз ретінде есептік-талдамалық, инвентаризациялық және салыстырмалы талдау әдістері қолданылды. Шығарындылардың мөлшері Қазақстан Республикасында қолданыстағы әдістемелерге сәйкес есептік жолмен анықталды.

Зерттеу нәтижелері бойынша кәсіпорында атмосфералық ауаға әсер ететін 17 шығарындылар көзі анықталды, олардың басым бөлігі қазандық агрегаттары, көмір қоймасы, күл-қож үйіндісі, жөндеу шеберханалары және сумен жабдықтау жүйелерімен байланысты екені көрсетілді. Атмосфераға түсетін ластаушы заттардың құрылымында қатты бөлшектер мен газ тәрізді қосылыстардың үлесі жоғары екені анықталды. Газтазарту қондырғыларының жұмысын талдау батареялық циклондардың қатты бөлшектерді ұстау тиімділігі жобалық көрсеткіштерге сәйкес келетінін көрсетті.

Алынған нәтижелер кәсіпорын аумағында атмосфералық ауаның сапасын тұрақты бақылаудың, ұйымдастырылмаған шығарындыларды азайтуға бағытталған шараларды күшейтудің және экологиялық басқару жүйесін жетілдірудің маңыздылығын дәлелдейді. Зерттеу деректері жергілікті деңгейде қоршаған ортаны қорғау іс-шараларын жоспарлау үшін ғылыми негіз бола алады.

Түйін сөздер: антропогендік әсер; атмосфералық ауа; шығарындылар көздері; экологиялық мониторинг; қазандық; газтазарту қондырғылары; өнеркәсіптік ластану.

Комплексная оценка антропогенного воздействия предприятия «Aitas-Energo» в Восточно-Казахстанской области на качество атмосферного воздуха

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Аннотация. В статье представлены результаты выявления основных источников антропогенного воздействия на окружающую среду и оценки их влияния на атмосферный воздух на предприятии «Айтас-Энерго», расположенном в посёлке Қасым Қайсенов Восточно-Казахстанской области. Целью исследования является инвентаризация организованных и неорганизованных источников выбросов на территории предприятия, определение их количественных и качественных характеристик, а также анализ эффективности газоочистных систем. В качестве материалов исследования использованы данные инвентаризации источников выбросов, проектно-технологическая документация,

отчёты производственного экологического контроля и технические характеристики оборудования. В качестве методической основы применялись расчётно-аналитический, инвентаризационный и сравнительный методы анализа. Величины выбросов определялись расчётным путём в соответствии с действующими в Республике Казахстан методиками.

По результатам исследования на предприятии выявлено 17 источников выбросов, оказывающих воздействие на атмосферный воздух, основная часть которых связана с котельными агрегатами, угольным складом, золошлаковым отвалом, ремонтными мастерскими и системами водоснабжения. Установлено, что в структуре загрязняющих веществ, поступающих в атмосферу, значительную долю составляют твёрдые частицы и газообразные соединения. Анализ работы газоочистных установок показал, что эффективность улавливания твёрдых частиц батарейными циклонами соответствует проектным показателям.

Полученные результаты подтверждают важность постоянного мониторинга качества атмосферного воздуха на территории предприятия, усиления мер, направленных на сокращение неорганизованных выбросов, а также совершенствования системы экологического управления. Данные исследования могут служить научной основой для планирования природоохранных мероприятий на местном уровне.

Ключевые слова: антропогенное воздействие; атмосферный воздух; источники выбросов; экологический мониторинг; котельная; газоочистные установки; промышленное загрязнение.