Analyzing the Impact of Dust Emissions from Metallurgical Enterprises on the Environment

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Abstract. The metallurgical industry is an integral part of the Russian economy. Therefore, the improvement of technological processes at enterprises and the expansion of the raw material base by involving new deposits and production waste pose a significant threat to the environment. The city of Shelekhov is one of the most polluted cities not only in the Irkutsk Region, but also in Russia. Based on the results of a study of various literary sources, it has been found that Shelekhov is a city with a high level of air pollution and a high concentration of emissions per person per year, which makes the problem under consideration relevant. In our work, we used the methodology for calculating atmospheric air pollution, in which the duration of exposure to concentrations exceeding the established standards was used as a criterion for assessing atmospheric pollution. Based on the results of the calculations, it was confirmed that the concentration of pollutants in the form of aerosols in the atmospheric air for a long time exceeded the established average daily maximum allowable concentration. As a result of the calculations, we made a schematic map of the distribution of impurities from stationary sources in Shelekhov. This affects the general well-being of the city’s population, primarily among children and adolescents. Based on the studies concerning the disease incidence of the population, it was found that over time, the overall rate of illnesses in children only increases, and the most frequent diseases are respiratory ones.

1. Introduction

The metallurgical industry is an integral part of the Russian economy. Therefore, the improvement of technological processes at enterprises and the expansion of the raw material base by involving new deposits and production waste pose a significant threat to the environment [1].

To produce one ton of products, more than three tons of primary natural resources of raw materials are involved in production [2-4]. As a result of smelting, blast-furnace slags are collected in sludge storages and dumps. They occupy urban and agricultural land areas, create an additional load on the soil.

There is evidence that metallurgy emits up to 25% of dust containing metal and carbon monoxide into the atmosphere from the total volume of these substances [4, 5]. Through the metallurgy production, about 50% of unprocessed sulfur oxides enter the atmosphere [6-8]. Also, a number of components harmful to humans are emitted into the atmosphere, including benzopyrene, vanadium, chromium and other elements.

Air pollution has a very negative impact on the health of the population who live near metallurgical enterprises. For example, in the Irkutsk Region, the city of Shelekhov with a population of 48 thousand people is located near metallurgical plants, such as IrkAZ-SUAL, Kremniy JSC, SUAL-PM LLC. This
is the reason for the spread of pathological diseases among residents living in this territory. This is evidenced by the numerous complaints of the population living in the polluted environment about unpleasant odors, headaches, general ill health and other uncomfortable conditions; medical statistics data indicating a tendency towards an increase in morbidity in contaminated areas; data from special scientific studies aimed at determining the quantitative characteristics of the relationship between environmental pollution and its effect on the body [9-12]. In this regard, the assessment of atmospheric air pollution and its impact on human health is one of the most important issues. The level of air pollution in the city is “very high”, determined by the concentrations of benzo(a)pyrene, ozone, suspended solids, nitrogen dioxide, hydrogen fluoride.

According to the state report The State of the Environment in the Irkutsk Region, the enterprises of the metallurgical complex in 2019 caused the pollution of the atmospheric air by emissions in the form of solid fluorides (2459 tons), inorganic dust containing oxides of silicon, aluminum, etc. (27 728 tons), resinous substances (2761 tons) and benzopyrene (2.8 tons). Annual average concentrations of sulfur dioxide, carbon monoxide, nitrogen oxide, solid fluorides, hydrogen fluoride, formaldehyde did not exceed the MAC, nitrogen dioxide was recorded at the MAC level. Average annual concentrations of suspended solids and ozone reached 1.1 MAC. The maximum of one-time concentrations exceeded the MAC: suspended solids – by 1.4 times, sulfur dioxide – by 1.2 times, carbon monoxide – by 1.1 times, nitrogen dioxide – by 3.0 times, nitrogen oxide – by 1.4 times, ozone – by 3.1 times, solid fluorides – by 1.3 times, hydrogen fluoride – by 2.0 times, formaldehyde – by 1.2 times.

The average annual concentration of particulate matter PM10 exceeded the MAC by 1.2 times, the maximum of the daily average – by 3.4 times. The annual average concentration of benzo(a)pyrene reached 6.3 MAC. The maximum of the average monthly concentrations was 19.1 MAC (January, recorded on Komsomolsky Boulevard). Concentrations of heavy metals (chromium, manganese, iron, nickel, copper, zinc, lead) did not exceed the established sanitary standards.

In 2019, 85 warnings were issued about high levels of air pollution during periods of unfavorable meteorological conditions, the forecast success rate of which was 100%.

Thus, the environmental situation in the areas affected by the aluminum and silicon industries remains extremely tense and it is necessary to take measures to improve it, minimizing the impact, reducing the environmental risk and eliminating the already accumulated sources of soil and ground surface pollution. Consequently, the purpose of our work was to study the impact of dust emissions from metallurgical enterprises on the state of the environment using the example of the city of Shelekhov.

2. Study objects and methods
The paper is modeling the distribution of anthropogenic emissions in the atmosphere using a mathematical model based on analytical solutions of the differential equation describing the transfer and turbulent diffusion of pollutants [13].

The considered mathematical model of the distribution of impurities in the atmosphere makes it possible not only to make a diagnosis, but also to predict changes in the ecological situation depending, for example, on the reconstruction of enterprises, a change in the type of fuel, a change in the operating mode, the commissioning of new facilities, the choice of an option for the optimal location of enterprises in terms of the least load on residential properties, ecologically significant areas, etc. [14].

The use of analytical solutions greatly simplifies the solution for the problem of impurity propagation and often gives rather interesting and important results. However, the analytical solutions themselves can be obtained only with significant simplifications of the studied processes [15-17].

Therefore, along with advantages, analytical solutions also have disadvantages. Thus, in cases of large slopes of the relief and thermal inhomogeneity of the underlying surface, it is possible to describe the propagation of impurities from the system of sources in detail only using numerical methods.

The use of this mathematical model makes it possible to calculate the duration of the impact of atmospheric air pollution on environmental objects, including humans [18]. Inventory data on the parameters of production sources were used as input information for the mathematical model: emission
intensity, coordinates of the relative location of sources, emission rate, temperature of the gas-air mixture, radius and height of the pipe [19].

As a result of the calculations, we made schematic maps of the contamination of the territory with plotted isolines drawn according to the frequencies of exceeding the average daily maximum allowable concentration in hours.

3. Results and discussion

Based on the mathematical model, taking into account climatic conditions, we mapped the city's territory, highlighting the areas most susceptible to contamination with various ingredients in terms of violation of permissible norms and the time of exposure of living organisms to toxic substances [20].

Calculations were made for aerosol emissions. According to the calculations, we made a schematic map of the distribution of pollutant impurities coming from metallurgical enterprises located in the city of Shelekhov.

Aerosol emissions in the form of inorganic dust with a silicon content of less than 20% and above 70%, resinous substances (pitch fumes) in the composition of electrolysis dust, as well as solid fluorides create hazardous concentrations for the population (Table 1).

| Pollutant                                               | Emitted into the atmosphere, t/year |
|--------------------------------------------------------|-------------------------------------|
| Inorganic dust with a silicon content of less than 20%  | 2415.65                             |
| Inorganic dust with a silicon oxide content above 70%   | 2302.86                             |
| Resinous substances (pitch fumes) in electrolysis dust | 325.42                              |
| Solid fluorides                                        | 594.27                              |

A particularly hazardous area from the point of view of atmospheric air pollution is the industrial site of IrkAZ SUAL OJSC, where the average daily MAC can be exceeded by up to 5-6 times (Figure 1).

Analyzing the resulting schematic map, it can be said that hazardous concentrations (exceeding the daily maximum allowable concentration) of harmful aerosols spread and reach the city's territory, mostly concentrating around the industrial sites of IrkAZ SUAL OJSC and Kremny JSC.
It was found that the main sources of environmental impact made by these enterprises are the electrolysis buildings of IrkAZ SUAL OJSC and the ore-heating department of Kremny JSC. The greatest impact on the atmospheric air is exerted by emissions through aeration lanterns.

To reduce the environmental load on the city of Shelekhov, it is necessary to introduce technological measures reducing emissions through aeration lanterns and chimneys of industrial buildings.

The main activities of the program are:
- Introduction of the best available technology (BAT) in accordance with the document ITS 11-2019 Aluminum production - Electrolysis in electrolysis cells with upper current supply to the anode;
- Increasing the efficiency of “dry” and “wet” gas cleaning plants and automatic supply systems;
- Increasing the efficiency of the shelters for electrolysis cells and ore-heating furnaces;
- Introduction of the technology of anode paste with a reduced PAH content;
- Measures to reduce the time/degree of depressurization of electrolysis cells and ore-heating furnaces;
- Increasing the extraction of silicon.

An assessment of the dynamics of reducing emissions in the form of aerosols emitted by metallurgical enterprises in Shelekhov is shown in Figure 2.

Figure 2. Dynamics of reducing the levels of air pollution in the residential area with marker substances.

Due to the implementation of the proposed measures, there is a decrease in the gross emissions of the main pollutants to the level of maximum allowable emissions.

4. Conclusion

The city of Shelekhov is one of the most polluted cities not only in the Irkutsk Region, but also in Russia, which invariably affects the overall morbidity of the population. Based on the results of a study of various literary sources, it has been established that Shelekhov is a city with a high level of air pollution and a high concentration of emissions per person per year, which makes the problem under consideration relevant.

Analyzing the data obtained, it can be said that hazardous concentrations (exceeding the daily maximum allowable concentration) of pollutants spread over almost the entire territory of the city.

This affects the general well-being of the city's population, primarily among children and adolescents, in the form of the most frequent manifestations of general morbidity and diseases of the respiratory system, which is due to the poor environmental situation in Shelekhov.
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