Methodical aspects of assessing the impact of industrial plants on air pollution

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Abstract. The article suggests that besides the established maximum permissible emissions of enterprises, which characterize air pollution from organized sources, emissions from "low" and unorganized sources, consider industrial sites as area sources. The authors propose a sequence of measures to reduce the impact of industrial sites as additional sources of pollution on the example of the aluminum production plant.

1 Introduction

The air quality of large industrial centers, despite the improvement of cleaning methods and measures for the reconstruction of production facilities, rarely meets the standard requirements. This article does not deal with urban air pollution by motor vehicle emissions. People limit the harmful impact of industrial enterprises by setting standards of maximum permissible emissions (MPE) [1, 2]. The normative characterizes the contribution of organized sources to atmospheric pollution. We can use the results of their dispersion in the atmosphere to determine the boundaries of sanitary protection zones.

The methodology [1] gives reliable results of calculation of dispersion of high and concentrated emissions, which enter the atmosphere through the systems of purification of technological and ventilation emissions. Industrial areas have much ventilation and other "low" emissions without treatment, which pollute the industrial areas and adjacent territories.

To combat atmospheric pollution, we propose to take additionally into account the impact of the industrial site as an area source of pollution. For such an assessment, we propose it to use the environmental standard of the industrial site, which considers the impact of enterprises on atmospheric pollution as an area source. It is recommended to take average daily concentrations of the key ingredients as the basic values for assessing the ecological standard of the industrial site.

It is especially important to develop an environmental standard for the site for facilities where aeration is the primary means of providing the standardized parameters of the air environment. Such facilities undoubtedly include metallurgical and aluminum smelters, where air exchange reaches hundreds of thousands of m^3/h.

The aeration volumes of industrial halls depend on the aerodynamic regime of the industrial site. Wind velocity and pressure fields influence the dynamics of ventilation processes, first, the calculated air exchanges. Circulation zones occur in the interstitial spaces and accumulate harmful substances discharged from aeration lanterns. Contaminated air from

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the inter-hull spaces through aeration openings flows back into the production facilities, reducing ventilation efficiency. Enterprises must solve the issues of aeration processes organization and assessment of the environmental standard of the industrial site, considering the production facilities and the atmosphere surrounding them as a single dynamic system [3,4].

It is especially important to determine the environmental standard for an industrial site when reconstructing enterprises or developing measures aimed at reducing urban pollution in industrial centers.

Correctly determining the environmental standard for an industrial site should include the following steps:

- provision of standardized parameters of the microclimate in the production facilities and sanitary and hygienic conditions in the standardization of air pollution by the average daily maximum allowable concentration (MAC);
- determining the level of air pollution at the industrial site, considering the aerodynamic regime and their layout;
- determination of the size and organization of the sanitary protection zone, limiting the impact of the industrial site on the residential area. Concentrations of harmful substances at the border of the sanitary protection zone should not exceed the maximum allowable concentration for residential areas.

The consistent solution to the above steps has the purpose of creating a methodology for determining the ecological standard of an industrial site.

Balance (integral) methods of calculation and empirical dependencies, reflected in the regulatory literature, help in providing microclimate parameters and air quality standards in industrial premises for various purposes in the design or reconstruction. This does not guarantee correct and energy-efficient solutions. We can get reliable information at each stage of development of the ecological standard of an industrial site by the method of mathematical modeling [5]. We should use the results of a full-scale survey of production buildings and industrial sites as input data in numerical modeling when reconstructing plants [6].

We present a sequence of determining the environmental standard of the industrial site and the analysis of the results on the example of the designed aluminum production plant, which has 4 identical parallel aluminum production buildings. Below is a comparison of the results of balance calculations and numerical simulations.

2 Methods

Modern studies of heat and hydrogasodynamic processes inevitably face the need for numerical experiments, replacing with success the labor-intensive laboratory experiments. The present work provides a numerical simulation of turbulent flows in the presence of heat sources and sinks, and gaseous dust impurities using the STAR-CCM+ program. The program allows solving the system of differential equations of Navier-Stokes, continuity, momentum conservation, energy transfer, and impurities [7,8]:

$$\frac{\partial \overline{p}}{\partial t} + \frac{\partial}{\partial x_j}\left(\overline{\rho u_i} + \overline{\rho' u_i'}\right) = S_m \quad (1)$$

$$\rho\left(\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j}\right) = -\frac{\partial \overline{P}}{\partial x_j} + \mu\left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_i}{\partial x_i}\right) + \frac{\partial \tau_{ij}'}{\partial x_j} + S_i \quad (2)$$

$$\frac{\partial(\overline{\rho a})}{\partial t} + \frac{\partial(\overline{\rho a u_i})}{\partial x_j} = -\frac{\partial\left(\rho\overline{u_j' a'}\right)}{\partial x_j} + \overline{J_a} \quad (3)$$

where t – time; ρ – density; μ – dynamic viscosity coefficient; $\bar{u}_j$ – components of averaged velocity vector along coordinate axes; τ_{ij} – turbulent stresses (additional Reynolds stresses); u'_i, u'_j, T', C' – local flow velocity, temperature and admixture pulsations; $\bar{a}$ – scalar specific density averaged values; S_m, S_i – mass and momentum source intensity; $\bar{J}_a$ – admixture source intensity (1; 2; 3).

3 Results

We determined the air exchange per building using both the balance methods without considering the aerodynamics of industrial sites and the numerical method, considering the distribution of dynamic pressure for summer and winter modes. Table 1 presents the results of calculations for the summer mode from the conditions of heat emission assimilation.

Table 1. Calculations of air exchange for the summer mode from the conditions of heat emission assimilation.

Calculation method, winter period	$L \cdot 106$, m^3/h	Maximum concentrations HF, mg/m^3	
		in a flashlight	in the work area
Star "SSM+" without pressure	19.1	0.12	0.03
Star "SSM+" at $\Delta P = 6$ Pa	21.9	0.11	0.15
Balance method	21.6	0.15	0.10

Note: ΔP - pressure drop in aeration openings due to wind flow, L - aeration air flow rate, maximum allowable concentrations of HF = 0.1 mg/m^3.

When using the balance method, air exchange for the summer period is 12% higher than the numerical calculation, and concentrations in the outgoing air are 20% higher.

Figure 1 clearly illustrates the effect of wind pressure on temperature distribution above the electrolyzer.

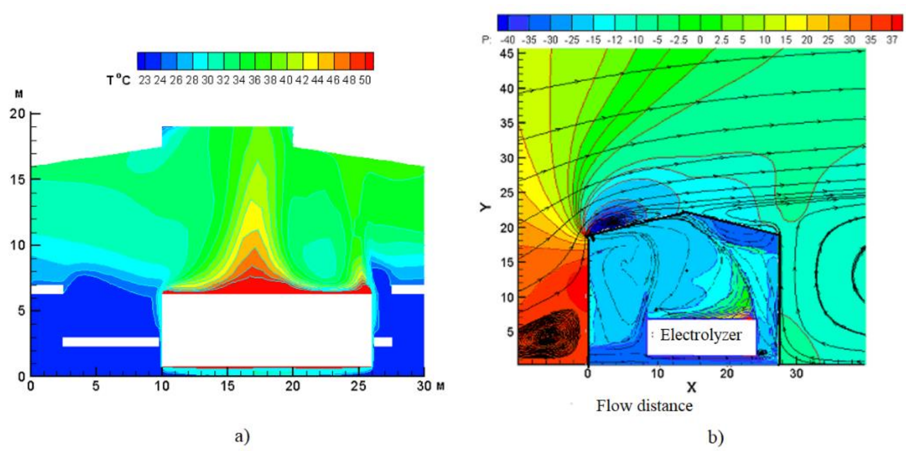


Fig. 1. Convective flow in the housing module from the electrolyzer: a - balance calculation; b - numerical simulation considering the dynamic pressure in the aeration openings.

Figure 2 shows the effect of dynamic pressure in the aeration openings on the air velocity fields in the aluminum housing module for the warm period of the year. Table 2 compares the results of numerical calculations. Windward pressure causes 7 times more air to enter the enclosure at a higher velocity. This has a significant impact on the distribution of hydrogen fluoride gas HF concentrations in the enclosure. The maximum concentrations exceed the MAC by 4 times.

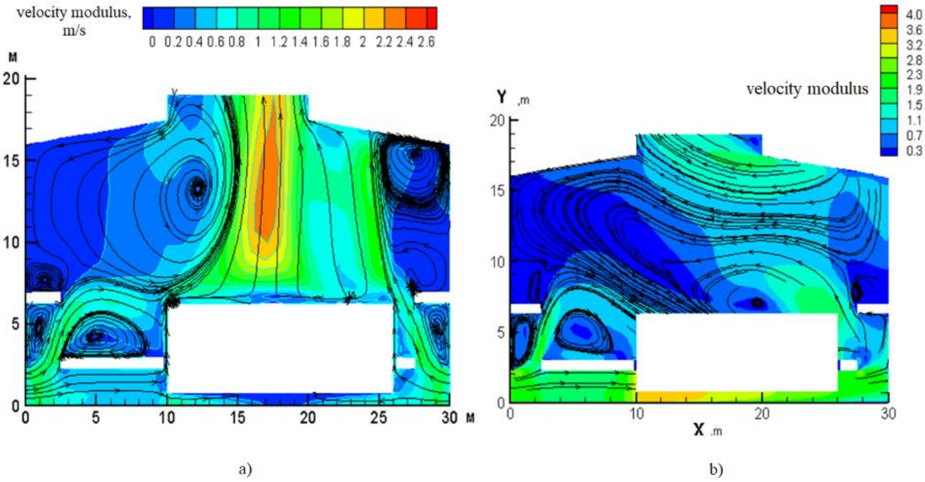


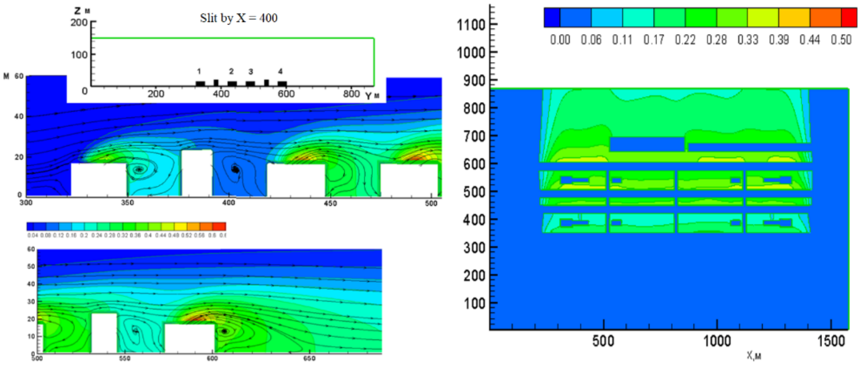
Fig. 2. Character of airflow in the aluminum section production shop module during the warm period: a - without considering the dynamic pressure in the aeration openings; b - with considering the dynamic pressure.

Table 2. Air flow rates and velocities in the aeration openings of the enclosure [4].

Calculation conditions	**Windward Side**		**Leeward side**	
	$L \cdot 10^6$, m^3/s	U, m/s	$L \cdot 10^6$, m^3/s	U, m/s
Without dynamic pressure	11.0	1.18	11.0	1.20
Considering dynamic pressure	19.3	2.50	2.60	0.33

Note: L, U - respectively, the flow rate and average velocity modulus, the maximum allowable concentration of HF = 0.1 mg/m^3.

We calculated the dispersion of emissions from aeration lanterns to assess the environmental standard of the industrial site. Hydrogen fluoride was taken as the key ingredient (maximum allowable concentration = 0.1 mg/m^3). Figure 2 shows the field of HF concentrations for a fragment of the industrial site and the current lines characterizing air movement. Concentrations of HF (mg/m^3) at the mouth of the aeration lanterns were taken from the calculation of the internal problem. We carried out calculations for different wind directions to choose the minimum level of pollution of the industrial site.



a) b)

Fig. 3. Fields of dimensionless concentrations at the industrial site of the aluminum smelter: a-vertical section of the field of HF concentrations and current lines characterizing air movement; b-horizontal section, wind direction is perpendicular to the longitudinal axis of the buildings.

The distribution of gaseous fluorine concentrations at the industrial site is not uniform. We recorded for the prevailing wind direction (angle α = 35o) a zone of maximum concentrations, localized (in the wind direction) behind buildings 1 and 2; values of HF concentrations without background - 0.05 mg/m^3. When the wind direction is perpendicular to the longitudinal axis of the buildings, pollution infiltrated the entire industrial site, and HF concentration values without background were 0.04 mg/m^3.

Analysis of the pollution of the industrial site of the plant designed to produce aluminum showed:

- the nature of pollution depends on the direction and speed of the wind;
- the maximum concentration of HF without regard to the background - 0.05 mg/m^3, which is 10 times higher than the maximum allowable concentration for inhabited areas (0.005 mg/m^3);
- values of the maximum allowable concentration in the project for HF concentrations at the industrial site = 0.1 mg/m^3.

The ventilation efficiency for each downstream industrial building, when the wind is perpendicular to the longitudinal axis of the buildings, decreases as the concentrations in the inter-hull spaces increase.Ventilation efficiency is 30% lower for enclosure 4.

Analysis of the pollution of the industrial site of the designed aluminum production plant showed that the average concentration is 3 times lower than the maximum allowable concentration (MAC = 0.1 mg/m^3), but 6 times higher than the single maximum allowable concentration = 0.005 mg/m^3 for inhabited areas.

Forecasting the environmental situation at the industrial sites allows us to determine correctly the boundaries of the sanitary protection zone, considering the prevailing wind directions, and ensuring the condition of the maximum allowable concentration for all ingredients for the settlements.

4 Conclusions

The article proposed a methodology for determining the environmental impact of industrial enterprises based on a comprehensive approach to the provision of standardized parameters of the microclimate in the production facilities and the permissible level of territory pollution, the definition of the boundaries of the sanitary protection zone. The methodology proceeds from the planning conditions and aerodynamic regime of industrial sites, considering the influence of all emission sources, based on the data of field studies and/or engineering calculations using numerical simulation.

Application of balance calculation methods allows to receive close numerical values, but cannot reveal spatial and temporal distributions of parameters.

The environmental standard of the industrial site will help in the fight against air pollution. The normative evaluates the impact of industrial sites as an area source, so we must consider it as an additional contribution of enterprises to atmospheric pollution.

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