Control of the efficiency of treatment of atmospheric emissions from power plants using the data on soil composition

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To check the efficiency of operation of treatment plants, the fields of one-time and long-term pollution of the environment in a source effective zone should be studied. In this paper, we use the regression dependence to describe long-term pollution of the environment. Our studies have shown that the reconstruction models adequately describe pollution of soil with chemical elements in a wide range of distances, and the background contents of different chemical elements vary significantly, hence, it is necessary to consider them when estimating the total fall.

Introduction

Many Siberian towns, even if they have no large industrial objects, are characterized by high degree of air pollution in winter. This is true, in the first turn, for towns and villages, in which coal is used for heating and the ambient conditions (cold temperatures, weak wind in combination with temperature inversions, complex terrain) are unfavorable for the pollutants dispersal. In such sites, smog is formed and large amounts of toxic coal combustion materials that are a serious hazard to human health are emitted.

Processes connected with burning of organic substances are accompanied by emissions of mutagenic and carcinogenic compounds, including heavy metals, polyaromatic hydrocarbons, etc. Direct measurement of such emissions and mathematical simulation of the pollution fields are complicated problems because of significant uncertainty in setting the emission rate and describing the processes of physical and chemical transformations of gas and aerosol media, as well as current meteorological conditions.[1–4]

A radical method of pollution control is the use of treatment plants. To check their efficiency, the fields of one-time and long-term pollution in the source effective zone should be studied *in situ*. To study one-time emissions, observations under the pollution plume should be organized under the variety of meteorological conditions, as well as various modes of emission and treatment are to be used. However, such observations are very expensive, and to lower the expenses, one should use the recommendations given in Refs. 6–8 that have passed evaluation tests at power plants, as well as some chemical and metallurgical enterprises.

Experimental study of the long-term pollution is somewhat simpler, because the needed meteorological information can be replaced with the climatic one. As a result, it becomes possible to interpret the data of *in situ* observations within the framework of rather simple mathematical models.[1,2,4,6]

1. Reconstruction of aerosol pollution of soil from observations

In Refs. 5 and 6 we have proposed, to describe the pattern of long-term pollution of a region with atmospheric aerosol emissions, the following regression dependence:

$$p(r, \varphi, \boldsymbol{\theta}) = \theta_b + \theta_1\, g(\varphi)\, r^{\theta_2} \exp(-2r_m/r), \quad (1)$$

where $p(r, \varphi, \boldsymbol{\theta})$ is the specific content of a pollutant in soil (snow, air); r and φ are the polar coordinates of a computational point with the origin at the place of the emission source; $g(\varphi)$ is the probability of the wind direction opposite to φ; r_m is the point of the maximum near-surface concentration for a weightless pollutant emitted by the given point source; $\boldsymbol{\theta} = (\theta_b, \theta_1, \theta_2)$ is the vector of unknown parameters.

The regression dependence (1) was obtained assuming a narrow (10–15°) plume. Its evaluation at some chemical and metallurgical plants has shown a good agreement with the experimental data.[2,5,6]

If we restrict ourselves to consideration of annually mean and winter-mean values of the wind velocity, air temperature, and turbulent exchange characteristic of this region, then, according to Ref. 7, the value of r_m can be estimated from the geometrical characteristics of sources and parameters of the emitted gas-vapor mixture. In particular, for the boiler house situated in Belokurikha the value of r_m is roughly 1 km.

The vector of unknown parameters $\boldsymbol{\theta}$ can be estimated from the data on the specific content of a

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pollutant at certain points of a region using, for example, the least squares method.[5]

The component θ_b describes the background concentration. The component θ_1 is proportional to the emission rate and has rather a complex structure depending on the climatic characteristics of the wind velocity, turbulent exchange coefficients, and sedimentation rates of aerosol pollutants.

The next component, θ_2, has the form

$$\theta_2 = -2 - w/[k_1(n+1)], \qquad (2)$$

where w is the sedimentation rate of aerosol particles; k_1 is the coefficient of vertical turbulent diffusion at the height of 1 m; n is the exponent in the approximation of the horizontal component of the wind velocity by a power-law profile. The case $\theta_2 = -2$ or $w = 0$ corresponds to a weightless pollutant, that is, $\theta_2 \le -2$. The optimal plan of observations for estimating the parameters θ_1 and θ_2 corresponds, according to Ref. 8, to the points spaced from the smoke stack by 0.5 and 1.5 km.

2. Experimental studies

As an object for the study, we have chosen the power plant in Belokurikha settlement (a town at the Altai Territory). This plant is the main source of atmospheric pollution in this region. The plant was recently equipped with new filters for treating atmospheric emissions, and thus the need arose to check up the efficiency of these filters.

One of the characteristics of long-term aerosol pollution of a region is the chemical composition of the surface layer of soil. To develop a program for checking-up new-generation filters, two missions were performed in May and June of 1998. The region of Belokurikha is well known due to its place of resort. The location of the object of our study with respect to the resort zone is very convenient from the viewpoint of optimal planning surface observations of atmospheric pollution and route sampling snow and soil. With respect to the prevailing wind, we have sampled surface soil in the northern direction at the distances multiple of 10, 20, 30, 40, and 50 source heights[8] (the stack height is 50 m). The soil was sampled from squares with the area of 25 m^2. Each square was divided into 10 sectors, at which the samples of 200 cm^3 were taken. Then these samples were mixed, and the sample for the square as a whole was chemically analyzed.

Semiquantitative analysis of the soil samples has been made at the Limnological Institute SB RAS by the ICP-MS method on a Plasma Quad II device (made by Vζ Elemental). This method allows identification of about 70 elements and their isotopic composition. One of the advantages of this method is low detection limit (DL) if compared with the detection limit of neutron-activated analysis. For most of the metals the DL is 0.01 ppb (μg/kg).

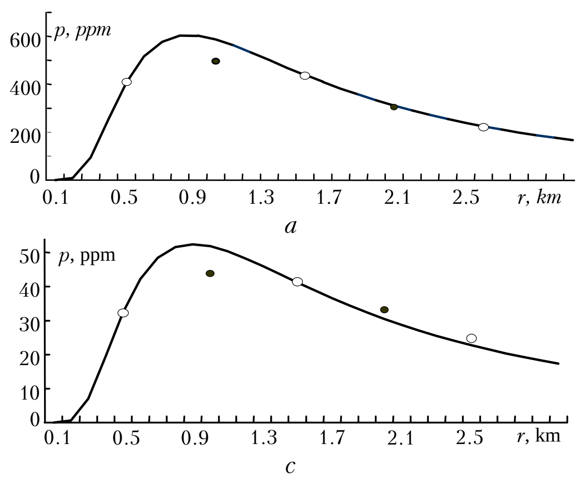
3. Numerical simulation

The experimental data obtained allow their interpretation by means of mathematical simulation. Using the dependence (1) and the observational data tabulated below, we can reconstruct the pattern of local pollution with some chemical elements.

Table. Estimated parameters of regression (1) for different chemical elements

Element	Estimated parameters		
	θ_b	θ_1	θ_2
Cs^{133}	1.5	20.4	−2.18
Fe^{54}	10000	214400	−2.3
Mn^{55}	340	43.35	−2.36
Th^{232}	0	151.4	−2.16
Bi^{209}	0	6.02	−2.24
Pb^{206}	0	13.89	−2.52
La^{139}	0	383	−2.21
Y^{69}	17	83.5	−2.18
Ti^{49}	2000	20606	−2.33
Tb^{159}	0.45	3.81	−2.16
Ce^{140}	20	701.2	−2.1

The results of reconstruction of the aerosol falling of chemical elements are shown in Fig. 1. This figure shows close agreement between calculations and measurements for the selected elements.



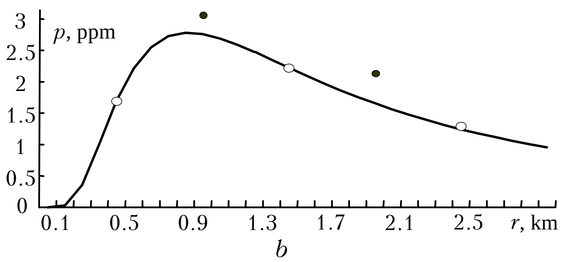


Fig. 1. Distribution of chemical elements depending on the distance from the source: numerical experiment (solid curve) and observations (dots); Mn^{55} (*a*), Cs^{133} (*b*), and La^{139} (*c*).

The tabulated data with the allowance made for the winter-mean wind rose allow us to obtain the lower estimate of the total emission from the power plant in winter season 1998/99. For some elements the background values are rather high, whereas for the other they are practically absent. The estimates of θ_1 allow us to find the relative total aerosol fall for the elements. The estimates of θ_2 show that the sedimentation rates of aerosol particles containing the considered chemical elements are mostly low.

Conclusions

The results obtained allow us to draw the following conclusions:

1. The reconstruction models adequately describe soil pollution with chemical elements in a wide range of distances.

2. Chemical elements are mostly deposited as a part of light aerosol fractions. In the case of high sedimentation rates, the models should be additionally modified and sampling points should be rearranged.

3. The background varies widely for different chemical elements, and it should be taken into account when estimating the total fall.

4. To estimate correctly the regression dependences and the total fall of chemical elements, monitoring of snow cover pollution in the vicinity of the power plant is needed.

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