CALCULATION OF THE CONTRIBUTION FROM EKIBASTUZ ELECTRIC POWER STATION INTO THE AIR POLLUTION OF WEST SIBERIA DUE TO THE LONG-DISTANCE TRANSFER OF THE EMISSION

V.A. Shlychkov

Institute of Water and Ecology Problems,
Siberian Branch of the Russian Academy of Sciences, Novosibirsk
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We formulate here the problem and present some results of integration of the numerical hydrodynamics model of the long-distance atmospheric transfer of sulfur and nitrogen compounds from Ekibastuz electric power station (EPS) (Kazakhstan) emissions. Three regimes of the EPS operation are considered: the existing regime, the possible one at the projected output without gas scrubbing equipment, and the regime with the extraction of sulfur and nitrogen compounds. The annual-mean fields of the contaminants' concentration obtained for each of the regimes, show that the influence zone of the EPS under an intense operation can cover a part of neighboring regions of Russia.

The problem of long-distance transfer of sulfur and nitrogen compounds is very urgent in West Siberia where highly developed heat and power industry emits a considerable amount of contaminating species into the atmosphere. Practically all the big industrial centers of the region are in the list of towns with a high level of air pollution. In the State report of the Environmental Protection Ministry "The state of the environment in Russian Federation in 1995" a number of West Siberian towns have been mentioned among the few with maximum high density of sulfur oxides precipitation.

In this connection the necessity arises of evaluating specific contributions coming from highly industrialized territories into the air pollution on a regional scale. In addition to estimations of the intensity of contaminating emissions from domestic (Russian) enterprises, it is of practical interest to reliably quantify the transboundary transfer of pollution from outside the Russian Federation.

As concerning the transboundary transfer from foreign enterprises the influence of Ekibastuz electric power production complex (Kazakhstan) with the maximum output power up to 8000 MW that emits more than 480 thousand tons of sulfur dioxide per annum is most significant. This source is located comparatively close to West Siberia regions.

STATEMENT OF THE PROBLEM AND METHOD OF SOLUTION

The flow of three-component impurity in the atmosphere over the territory with the dimensions of 2000 km along each horizontal axis, x and y, is considered. The geographical orientation of the rectangle is chosen so that it covers Ural, the southern regions of West Siberia, and a part of Kazakhstan territory, including Ekibastuz (see the figure). The system of equations describing the transfer of an impurity in the boundary layer of the atmosphere has the following form:

$$\frac{\partial C_1}{\partial t} + u\,\frac{\partial C_1}{\partial x} + v\,\frac{\partial C_1}{\partial y} =$$

$$= E_1 - (k_1 + m)C_1 + \frac{\partial}{\partial z}\,\nu\,\frac{\partial C_1}{\partial z} + \Delta C_1\ ,$$

$$\frac{\partial C_2}{\partial t} + u\,\frac{\partial C_2}{\partial x} + v\,\frac{\partial C_2}{\partial y} =$$

$$= \beta\, m\, C_1 - k_2 C_2 + \frac{\partial}{\partial z}\,\nu\,\frac{\partial C_2}{\partial z} + \Delta C_2\ , \qquad (1)$$

$$\frac{\partial C_3}{\partial t} + u\frac{\partial C_3}{\partial x} + v\,\frac{\partial C_3}{\partial y} = E_3 - k_3 C_3 + \frac{\partial}{\partial z}\nu\frac{\partial C_3}{\partial z} + \Delta C_3\ ,$$

where t is time; z is the vertical coordinate; C_1, C_2, and C_3 are the fields of concentrations of sulfur dioxide, SO_2, sulfurous acid plus sulfates, SO_4^{2-}, and nitric oxides NO_x, respectively; u and v are the horizontal velocity vector components; E_i is the power of emission sources; k_i are the rates of the impurity's components washing out by precipitation; m is the rate of chemical transformation of SO_2 into the sulfates; β is the ratio of the molecular mass of SO_4^{2-} and SO_2; ν is the vertical diffusion coefficient; Δ is the operator of the horizontal diffusion.

Boundary conditions along the vertical direction may be written in the following way:

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$$\nu \frac{\partial C_i}{\partial z} = \gamma_i C_i \quad \text{for } z = 0;$$

$$C_i \to 0 \text{ for } z = \infty, \qquad (2)$$

where $i = 1, 2, 3$; γ_i is the velocity of dry (surface) sedimentation. Boundary conditions on the sides are specified for the inflow only by assuming that the substance concentration there is known and equals to the background value.

As the initial conditions we take that

$$C_i = 0 \quad \text{for } t = 0. \qquad (3)$$

Description of the horizontal diffusion is assumed to be different for two variants: one is connected with calculation of averaged over certain time (month, year) concentration fields (climate regime), and the other variant is the calculation (prognostic mode) of a concentration field for an actual velocity field during the current time interval. In the climate regime the horizontal diffusion is assumed to be caused by the spread of trajectories about the statistically mean in the sense of averaging over an ensemble of synoptic processes during the period of averaging. In this case the diffusion is introduced by analogy with the Fick representation in the following form:

$$\Delta C_i = \mu \left(\frac{\partial^2 C_i}{\partial x^2} + \frac{\partial^2 C_i}{\partial y^2} \right), \qquad (4)$$

where μ is the coefficient of horizontal diffusion. Calculation of a concentration field from an individual impurity jet assumes a non-classical description of the diffusion that may be introduced phenomenologically by the horizontal stretching of the jet segments.[1]

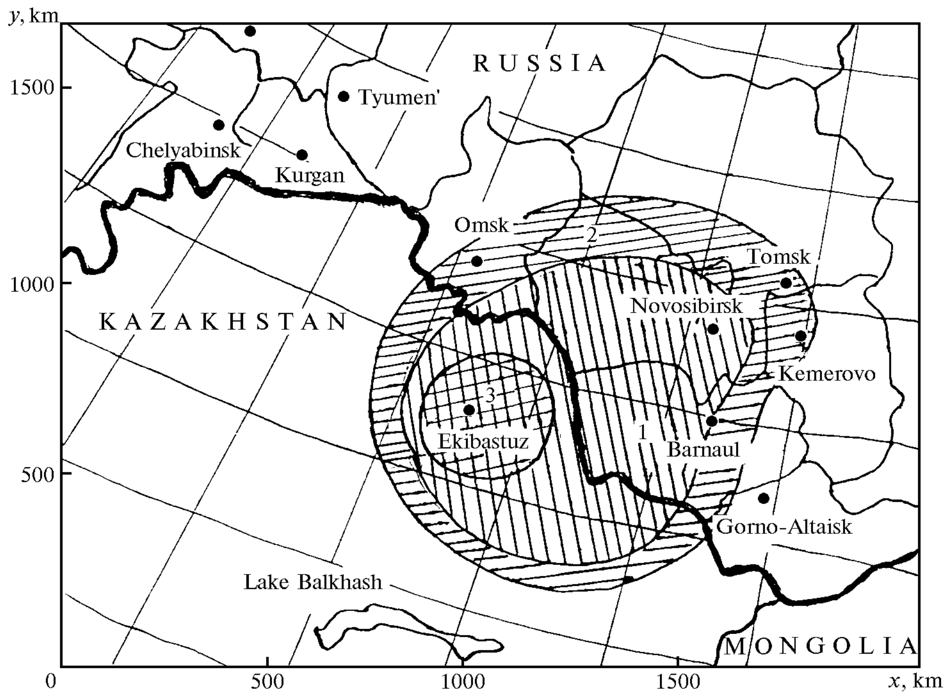

FIG. 1. The influence zones of the Ekibastuz EPS for three operation regimes.

The methodological basis is, in this case, oriented toward the model of Meteorological Synthesizing Center "Vostok" (MSC–V) used at present for operative purposes in European countries and in Russia[2] to obtain the integrated estimates of the transboundary flows. The model is of a hybrid (Euler–Lagrangian) type with a single-layer numerical-analytical description of the vertical structure of the impurity field. Moreover, any unknown function from (1) is presented as a product

$$C_i = Q_i(x, y, t)\, \varphi_i(z, t), \qquad (5)$$

where the first factor is defined on a discrete set of nodes of a horizontal grid and is the sought value, and a specific form of the second factor is given *a priory* as known solution to the heat equation with the parameters depending on time only.

Thus obtained system is solved numerically by the splitting method. At the first stage the calculation of trajectories and determination of the center of mass inside a cell of the grid area are performed based on Lagrangian representation. In this case the basic equations are completed by relations for the first moments that are equivalent to the initial equations in the differential form, and allow one, if discretized, to determine the coordinates of the center of mass of every substance.

Transferred mass may be represented in two ways: to calculate the advection, it is centered at a point (center of mass), while in order to introduce the diffusion, its interpretation as uniformly distributed over an elementary grid element is used. This allows us to realize a geometrical expansion of the mass-element area in a given proportion with the corresponding decrease of concentration to simulate the diffusion. Since in this case several adjacent cells are "covered" every partial mass, when projected on the grid is attributed to its own grid element and is summed up with the mass that has come to the cell earlier. The center of total mass is calculated by the weighted summation. At the stage of integration over z the effects of dry sedimentation are taken into account and parameters of vertical distribution are determined.

The next stage of splitting describes the moist removal and chemical transformation of SO_2 into sulfates. The impurity transformations taken into account in the model are as follows. The emitted sulfur dioxide, during the redistribution in the space due to the advection, diffusion, and vertical stirring, is partially absorbed by the underlying surface, the other part being transformed into the sulfate-ions and precipitates with rain, snow, etc. The sulfates formed undergo, along with the transfer and diffusion, a dry and moist sedimentation. The calculations made show that if the concentration of the initial substance (SO_2) decreases monotonically with the distance from a source then the content of secondary products increases along the plume axis and reaches its maximum at a distance of 500–1000 km from the emission center, depending on the transfer velocity and on the precipitation field. These estimations well agree with the data of acid precipitations monitoring.[1]

Let us present the values of numerical and physical parameters used. Since the vertical structure of the concentration field is given in a parametric representation as analytical functions the digitization is performed in the plane (x, y). The problem is solved on the grid including 55×55 square cells with the side of 37.5 km. The data on the effluent volumes in different seasons were taken from the specifications of the Ekibastuz EPS. Meteorological data on the annual behavior of wind and precipitations were taken from the climate reference books for the regional centers that are located in the region under study. These data were linearly interpolated on the grid used.

Quality of representing the spatial structure was studied by comparing numerical solution of the equations and fields of the exact solution obtained under the assumption that the process is a steady state one and all parameters being uniformly distributed over the horizontal plane. A concrete form of the solution may be found in Ref. 3 and it is a combination of the elementary functions and modified Bessel function. For the above values of spatial resolution parameters the relative error at the distances more than 200 km from a source was less then 3%. When the advection velocity increases, the error also shifts along the transfer direction while remaining sufficiently small. Thus the numerical model is considered as adequate to the initial statement of the problem.

CALCULATED RESULTS

The following circumstance made a motivation for this study. Ekibastuz electric power production complex that was built on the territory of Kazakhstan includes two stations: EPS–1 and EPS–2. The EPS–1 built in 1974 can run into the power of 4000 MW. When EPS–2 is put into operation with the same or higher output, the volume of contaminants emitted into the atmosphere will strongly increase. Part of these contaminants will get, due to the western transfer, to the Russian territory and can worsen the ecological situation in the neighboring regions. The proposed installation at the EPS of modern equipment for the extraction of sulfuric and nitric compounds could allow the volume of atmospheric emissions to be considerably decreased. According to this fact three variants of the EPS operation will be considered below: 1) the existing regime, 2) the prospective regime without additional gas scrubbing equipment 3) the regime of operation with the gas scrubbing equipment.

Stationary concentration fields are obtained by calculations for the three operation regimes. The calculations were targeted at obtaining a set of individual concentration fields of some ingredients using the set of parameters related to every month of a year by further summing of these fields with weight coefficients characterizing the frequency of occurrence of the concentration values. This procedure recurred for every of 8 points of the compass of wind direction, and the concentration sum over the wind rose was just the annual mean value sought.

Calculated annual mean concentrations were used as a basis to select the regions of the Ekibastuz EPS's influence. The one percent level of the daily mean maximum permissible concentration was selected as a criterion to obtain the influence zones for the sulfur dioxide.

The figure presents the influence zones of the Ekibastuz EPS's for the above three operation regimes (the regions 1, 2, 3, respectively). The influence zones are obtained for the calculated annual mean concentration fields of all ingredients considered as reduced to a complex index which is the atmospheric pollution index.[4]

One can see that under the regime of existing operation (region 1) the influence zone covers considerable parts of the territory of Novosibirsk and Altai regions. If both stations will reach the design output, practically all these territories will be under the influence of pollutions from this station (region 2). In this case about 40% of Omsk region and a part of Tomsk and Kemerovo regions will also be "covered" by the plume. The total area subject to the EPS influence on the territory of Russian Federation is 249 and 423 thousand km^2 for the regions 1 and 2, respectively. Note, that about 60% of the West Siberian territories are the agricultural lands and 30% of those are forests.

Large portion of the water catchment area of the upper Ob' is in the influence zone of the Ekibastuz EPS. The sulfur accumulated in the blanket of snow during the spring flood comes to the river-bed net. According to model estimations, the fraction of the total sulfate influx coming from the Ekibastuz EPS is 17–30%.

When the effective clearing equipment is installed the influence zone does not exceed the boundaries of Kazakhstan (the region 3 in the figure).

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