MAXIMUM CONTAMINATION LEVELS IN THE CITIES UNDER CONDITIONS OF THE SYNOPTIC AIR STAGNATION

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The maximum contamination levels are observed in the cities under conditions of the air synoptic stagnation at gentle breeze and ground temperature inversion. We describe a theoretical method for determination of toxic substances in the cities at the synoptic air stagnation as well as the calculation of maximum contamination concentrations in some Siberian cities where the synoptic air stagnation is often observed.

To assess the urban ecological conditions, the determination of the atmospheric contamination level is of great practical importance. The contamination level is first determined by the amount of atmospheric emissions of different industrial enterprises. However, the meteorological conditions are also of primary importance. Sometimes the meteorological conditions take place when at one and the same emissions the gaseous contamination concentration in the air increases many-fold.

Among these meteorological conditions there are, in particular, the synoptic situation of air stagnation when the ground temperature inversion is observed at wind velocity of 0–1 m/s. Such a situation often occurs in the stationary anticyclones. The highest occurrence of the situation with air stagnation is observed in Siberia (Table I).[1] It follows from this table that in winter the frequency of occurrence of this situation, for example, in Irkutsk is 55%, and in Chita it is even 68%.

TABLE I. Frequency of occurrence (%) of synoptic situations of air stagnation at wind velocity of 0–1 m/s *at the ground surface and in the presence of ground inversion in the cities of Siberia.*

City	Month			
	January	April	July	October
Omsk	14	10	15	8
Novosibirsk	15	8	10	4
Krasnoyarsk	47	22	31	30
Bratsk	39	32	34	14
Irkutsk	55	14	16	29
Chita	68	24	23	41

Such situations take place also in other areas of Russia, e.g., in Moscow their occurrence in spring is 30%.

High levels of toxic substances' concentration are especially dangerous for the human health and environmental conditions, therefore considerable attention should be given to the study of the methods for assessing toxic concentrations under the above-mentioned conditions. However, these methods have not yet been developed for practical purposes. The paper by M.E. Berlyand and O.I. Kurenbin should be mentioned where the method is proposed for calculating the toxic concentrations under calm[2] conditions .

This paper presents a simple and efficient method of calculation of toxins concentration under calm and ground inversion conditions simultaneously, i.e., under synoptic conditions of air stagnation. The method is based on solution of a simplified equation of the admixture balance,[3,4] which, as applied to the values averaged over the layer of vertical mixing (LVM) of the thickness H or over the ground layer of the thickness h, may be written as

$$- k_1 \Delta s + \sigma s = E, \qquad (1)$$

where s is the substance concentration, k_1 is the coefficient of turbulent viscosity at the horizontal transportation; $\Delta = \partial^2/\partial x^2 + \partial^2/\partial y^2$ is the Laplacian operator; E is the inflow or sink of gaseous contamination, that is, the rate of the inflow and disappearance of impurity; $\sigma = \beta/H$ or $\sigma = \beta/h$ (here β is the rate of impurity absorption by the ground surface).

Equation (1) is the nonhomogeneous Helmholtz equation. The simplest exact solution of this equation may be obtained for the circular region of radius $r = R$ under boundary condition

$$s = \overline{s} \text{ at } r = R, \qquad (2)$$

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where the bar denotes the averaged value s at $r = R$.

The equation solution in the polar coordinate system (r, φ) under conditions (2) may be written in the form[5]

$$s(r = 0) = \frac{1}{2\pi} \int_0^{2\pi} \int_0^R \frac{E}{k_1} G_1 \, r \, \mathrm{d}r \, \mathrm{d}\varphi + G_2 \, \bar{s}, \quad (3)$$

where G_1 and G_2 are the functions of influence. Taking the average over the area of a circle value $\bar{e}$ outside the integral sign and assuming that

$$\frac{1}{2\pi} \int_0^{2\pi} G_1 \, r \, \mathrm{d}r \, \mathrm{d}\varphi = c_1$$

and $G_2 \, \bar{s} = c_2 \, s(r = 0)$, Eq. (3) can be written as

$$s(r = 0) = (1 - c_2) \, c_1 \, \bar{e} \, . \quad (4)$$

In this case the coefficients c_1 and c_2 can be determined based on the solution of Eq. (3). However, the coefficients can be found using the least squares method.

The simplest solution of Eq. (1) can be obtained using numerical methods. Now we consider the case of a square area $Q = (2\delta)^2$, where δ is the step of the net. If the points $i = x/\delta$, $j = y/\delta$ then for the point $r = 0$ $(i = j = 0)$ we have

$$\Delta s = \frac{1}{\delta^2} (s_{1,0} + s_{-1,0} + s_{0,1} + s_{0,-1} - 4s_0),$$

where $s_0 = s(r = 0) = s_{00}$. Then considering that $s_{1,0} = a_1 \, s_{00}$, $s_{-1,0} = a_1 \, s_{00}$, $s_{0,1} = a_1 \, s_{00}$, and $s_{0,-1} = a_1 \, s_{00}$, where a_1 is the coefficient, instead of Eq. (1) we obtain

$$\frac{k_1}{\delta^2} (-4a_1 \, s_0 + 4s_0) + \sigma s_0 = \bar{e} \, .$$

Hence it follows that

$$s_0 = \left[(1 - a_1) + \frac{\sigma\delta^2}{4k_1} \right]^{-1} \frac{\delta^2}{4k_1} \, \bar{e} \, . \quad (5)$$

In the case of large δ values and small k_1 we have

$$\frac{\sigma\delta^2}{4k_1} \gg (1 - a_1).$$

And then

$$s_0 = \bar{e} \, / \sigma. \quad (6)$$

Because $E = \dfrac{M_t(1 - \gamma)}{Qh}$, where $M_t = M/T$ is the source power; l is the mass of emitted contaminants; T is the time when we consider the emissions ($T = 3.11 \cdot 10^7$ s, year); γ denote the percentage of a given contamination, which transforms into the other one just after the emission ($\gamma = 5$–10), we obtain

$$s_0 = \frac{M_t(1 - \gamma)}{Qh} \frac{h}{\beta} = \frac{M_t(1 - \gamma)}{Q\beta} \, . \quad (7)$$

Table II gives the values of s_0 under air stagnation condition calculated for some Siberian cities using Eq. (7). In what follows these maximum values of s_0 are denoted as s_m, i.e., $s_\mathrm{m} = s_0$. Table II also shows the calculated values of annual emissions in the cities.[6]

When considering the data from Table II we emphasize that in all the cities the above values are close to maximum permissible concentrations or exceed these concentrations (both daily mean and maximum ones). The excess is double fold and even more. This has been demonstrated most clearly in Novokuznetsk where the excess over maximum permissible concentrations (MPC) takes place for all the ingredients (except for hydrocarbon). Note that the MPC excess in nitrogen peroxide takes place in all the cities. Considerable excess of the level of MPC was revealed from the data of direct measurements.[7]

Unlike the situations of air stagnation the toxins' concentrations calculated under standard climatic conditions turned out to be small, of the order of 1/10 – 1/20 MPC (at the same emissions in all the cities where the measurements were made). These estimates were obtained using the following expression:

$$s = M_t(1 - \gamma) / (H \, \bar{u} \, d), \quad (8)$$

where H is the height of the vertical mixing layer; $\bar{u}$ is the mean wind velocity in the layer; d is the horizontal extension of the city. As an example Table II shows the toxins' concentrations calculated for the conditions of January ($H = 600$ m) and July ($H = 1100$ m) in Tomsk.

It follows from Table II that the cities of Siberia under standard (climatic) conditions are relatively "ecologically clean".

Thus the method proposed has made it possible to assess the maximum levels of air pollution under the air stagnation synoptic conditions. The air pollution in Siberian cities under these conditions is very strong, the contaminant concentrations are close to the maximum permissible values or exceed those values.

TABLE II. Emissions of toxins, M, thousand tons/year *(the net weight relative to the city area); maximum concentrations of toxins under the air stagnation conditions,* s_m, μg/m^3, *in the cities of Siberia. The toxins' concentrations in Tomsk corresponding to climatic conditions in January,* s_{Ja}, and in June, s_{Ju}, μg/kg. *Daily mean and maximum single permissible concentrations of toxins – MPC*$_{dm}$ *and MPC*$_{ms}$, μg/kg.

City, area, km^2, population, thousand people	Value	Toxins				
		solid	sulfur dioxide	nitrogen peroxide	carbon monoxide	hydrocarbon
Omsk	M	90.1	124.6	43.6	112.2	–
438; 1166	s_m	658	910	324	8210	–
Novosibirsk	l	57.6	45.9	35.0	141.0	–
483; 1418	s_m	384	303	233	930	–
Tomsk	l	16.8	4.0	10.5	59.6	0.6
163; 445	s_m	320	79	206	1140	11.8
Novokuznetsk	l	94.5	53.2	32.3	390.4	0.2
291; 619	s_m	1030	586	362	12500	0.22
Krasnoyarsk	l	37.2	35.4	25.2	221.7	–
376; 913	s_m	358	304	216	18900	–
Bratsk	l	41.6	15.9	7.6	80.4	0.3
100; 265	s_m	1270	500	244	2580	9.6
Irkutsk	l	12.5	16.5	10.8	47.7	0.5
175; 617	s_m	229	303	196	875	8.2
Chita	l	27.2	24.5	10.5	69.4	0.1
473; 370	s_m	184	166	70	483	0.7
Tomsk	s_{Ja}	13.4	3.2	8.3	45	0.47
	s_{Ju}	7.2	1.7	4.5	25	0.25
	MPC$_{dm}$	150	50	40	3000	3
	MPC$_{ms}$	500	500	85	5000	12

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