SOME REGULARITIES OF IRKUTSK AREA POLLUTION BY POLYCYCLIC AROMATIC HYDROCARBONS

V.F. Raputa, T.V. Khodzher, A.G. Gorshkov, and K.P. Kutsenogii

Institute of Computational Mathematics and Mathematical Geophysics, Siberian Branch of the Russian Academy of Sciences, Novosibirsk
Limnological Institute of the Siberian Branch of the Russian Academy of Sciences, Irkutsk
Institute of Chemical Kinetics and Combustion, Siberian Branch of the Russian Academy of Sciences, Novosibirsk
Received February 4, 1998

A simple regression model of environmental pollution is proposed based on the solution to the semiempiric equation of turbulent diffusion. The model is evaluated using the data of route snow photography. A relation is established between the levels of pollution on route and the mean winter recurrence of wind directions.

INTRODUCTION

Very often, when solving various problems on air pollution, quite a limited number of factors can be isolated that are very critical in the formation of the concentration levels of the contaminating species. Unless otherwise justified, for instance based on the analysis of the data available, making the model of an admixture dispersal too complicated can give rise to unwanted interference in calculations.

Taking this into account, the model of long-term contamination of the territory that is far from the sources of atmospheric emissions is discussed. The basis for the model is formed from certain properties of the turbulent diffusion equation solutions, in the atmospheric mixing layer, which provide for making the requirements to the meteorological information and to the data on the emission sources needed not so strict.

Based on the approach proposed we have interpreted the data on snow cover contamination with the polycyclic aromatic hydrocarbons (PCAH) collected on the territory nearby Irkutsk city.

At some control points along the routes from Irkutsk to Listvyanka and from Irkutsk to Bayandai we have achieved quite a good agreement between calculated results and the data of observations. Using data of aerological soundings of the boundary atmospheric layer over Irkutsk in winter we have revealed a correlation between the level of snow contamination with PCAH along these routes and the winter mean recurrence of wind directions at heights above 100 meters.

1. STATEMENT OF THE PROBLEM

The results of theoretical and experimental investigations of light impurity propagation in the boundary layer of the atmosphere show[1–3] that at a 7 to 10 km distance from the emission source the height of source does not practically affect the concentration level, both near the underlying surface and in the entire mixing layer. The concentration of an impurity at such distances from a stationary source can sufficiently accurate be estimated by the following formula[2,3]:

$$q(x, y) = Q/(\sqrt{2\pi}\, u\, H\sigma_y(x))\, e^{-y^2/2\sigma_y^2}, \qquad (1)$$

where $q(x, y)$ is the near-surface concentration, Q is the emission source power, u is the wind speed along x axis, H is the mixing layer height, $\sigma_y(x)$ is the function, describing transverse diffusion of the impurity.

The expression (1) describes the asymptotic behavior of a solution to the semiempirical equation of the turbulent diffusion of a light impurity at large distances from its source. It is also assumed that the impurity reflects, when spreading, from the underlying surface and from the upper boundary of the boundary atmospheric layer without any transformations. Under stationary conditions, the impurity concentration only changes, at a large distance, due to the widening of the emission plume across the wind.

Averaging of the impurity concentration over a long time (month, season, year), can certainly be done using climatic data on the wind velocity instead of a current meteorological information. In that case the concentration will be defined, with the account of equation (1), by the following relation[4,5]:

$$q(r, \varphi) = P(\varphi)\, Q/(2\pi\, r\, u\, H). \qquad (2)$$

Here r and φ are the polar coordinates, whose origin coincides with the emission source position, $P(\varphi)$ is the probability of wind direction to have the opposite to φ sign.

In the case when there are M emission sources, the total concentration field is presented in the following way:

$$q(x, y) = \frac{1}{2\pi\, uH} \sum_{k=1}^{M} \frac{Q_k\, P(\varphi_k(x, y))}{r_k(x, y)}\,, \qquad (3)$$

where

$$\varphi_k(x, y) = \arctan \frac{y - y_k}{x - x_k} ; \quad (4)$$

$$r_k(x, y) = \sqrt{(x - x_k)^2 + (y - y_k)^2}, \quad k = \overline{1, M} ;$$

x_k and y_k are horizontal Cartesian coordinates of the emission sources. At large distances from an industrial center the values of the impurity concentration are usually taken according to the relation (2), in which Q is the total emission outcome, r is the distance from the point of observation to the center of mass of the emission sources.

Assuming the field of precipitation density $G(r, \varphi)$ to be proportional to the impurity concentration in air, we obtain, with the account of the above, the following simple regression relationship:

$$G(r, \varphi) = \theta\, P(\varphi)/r, \quad (5)$$

where

$$\theta = \lambda Q/(2\pi\, uH);$$

λ is the coefficient of the impurity interaction with the underlying surface. The unknown parameter θ can be estimated based on the data of precipitation density observations.

Remark 1. As follows from the regression relationship (5), an optimal point for making observations that could ensure the highest accuracy of the sought parameter estimation[6] must be close enough to the territory of an industrial zone of a town being chosen taking into account for the highest recurrence of the wind directions. It also must not suffer from the influence of local emission sources.

Remark 2. Formula (3) may readily be generalized for the case of a continuous distribution of the impurity emission over the entire territory under study. The similarity of equation (3) to the view of the potential of a system of material particles, accurate to the notations, enables one to use the theory of potential for studying the system asymptotic properties.[7]

2. ANALYSIS OF ROUTE OBSERVATIONS

The snow samples have been collected in winter of 1995/96 along the routes 1) from Irkutsk to Listvyanka, 2) from Irkutsk to Bayandai, and 3) from Irkutsk to Slyudyanka.

Preliminary analysis of the data obtained has revealed that on the whole the rate of the PCAH sedimentation monotonically decreased along the routes 1 and 2. At the same time it was found that many points of sampling along the route 3 suffered from direct influence of the local emission sources in Shelekhov town. Therefore we will focus our further consideration on the measurement data obtained along the routes 1 and 2.

In Tables I and II the estimations of the rates of PCAH accumulation along these routes are presented as obtained using the regression formula (5). The center of Irkutsk city was chosen as an aggregated center of the PCAH emission. When making the calculating we have used the following additional designations:

$$\theta_L = \theta\, P(\varphi_L), \quad \theta_B = \theta\, P(\varphi_B), \quad (6)$$

where φ_L and φ_B are the angles, characterizing, correspondingly, the directions of routes to Listvyanka and Bayandai.

TABLE I. The rates of PCAH accumulation along the route from Irkutsk to Listvyanka (μg/m^2) *per week.*

Sampling point No.	Distance from the city center, km	PCAH			
		Phenanthrene	Fluoranten	Pyrene	Benz(a)pyrene
1	7	4.4*/4.4	2.1*/2.1	2.9*/2.9	0.4/0.86
2	12	2.3/2.6	1.3/1.22	1.7/1.69	0.5*/0.5
3	23	0.9/1.3	0.7/0.64	0.7/0.88	0.2/0.26
4	31	0.9/1.0	1/0.47	0.5/0.65	0.3/0.2
5	45	1.1/0.7	1/0.33	1/0.45	0.4/0.13
Estimate of θ_L		30.8	14.7	20.3	6

Comments: figures before the slash are measurement data and after the slash the calculated ones; asterisk denotes data taken for calculating the parameter θ_L.

TABLE II. The rates of PCAH accumulation along the route from Irkutsk to Bayndai (μg/m^2) *per week.*

Sampling point No.	Distance from the city center, km	PCAH			
		Phenanthrene	Fluoranten	Pyrene	Benz(a)pyrene
1	15.3	0.8*/0.8	0.5*/0.5	0.6*/0.6	0.2*/0.2
2	32.5	0.3/0.38	0.1/0.24	0.3/0.28	0.1/0.09
3	65.5	0.4/0.19	0.2/0.12	0.2/0.14	0.02/0.05
4	89.5	0.2/0.14	0.1/0.09	0.1/0.1	0.02/0.03
5	114.5	0.4/0.1	0.3/0.06	0.4/0.08	0.2/0.02
Estimate of θ_B		12.2	7.7	9.2	3.1

See comments to Table I.

Analysis of data given in Table I shows that, on the whole, not so bad agreement takes place between the calculated and measured data at the control points No. 2 to No. 4, except for benz(a)pyrene. Noticeable discrepancy at the point No. 5 is caused by additional contribution from Bolshaya Rechka settlement.

From the analysis of data given in Table II, it is seen a good agreement between the estimates of pyrene and benz(a)pyrene at the points No. 2 to No. 4 and of the phenanthrene and fluoranten at the point No. 4. Increase in the PCAH sedimentation rate at the point No. 5 is caused by the close location of Bayandai populated area. To elucidate the causes of an essential discrepancy (with accuracy up to reverse) of the estimates of observations at the point No. 2 and No. 3 of phenanthrene and fluoranten need for further investigation.

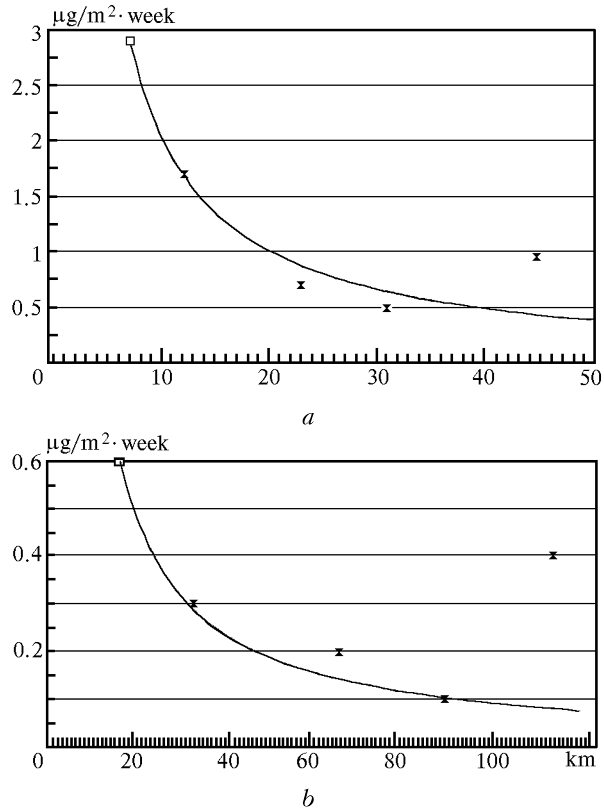

FIG. 1. The rates of pyrene sedimentation along the routes from Irkutsk to Listvyanka (a) and from Irkutsk to Bayandai (b).

In Fig. 1 the estimated and measured data on the sedimentation rates of pyrene along the routes 1 and 2 are presented.

From the comparison of these estimates and climatic data, presented in Table III, one may see the relation of the pollution levels to the recurrence of wind directions at the height above 100 m. The rates of the PCAH sedimentation observed along the second route are approximately two times lower than those along the first one.

TABLE III. Recurrence of wind directions (%) at different heights.

Wind direction	Height, m				
	Wind vane	100	200	500	1000
South	5	15	23	18	12
South-West	2	4	7	11	11
West	7	8	7	11	15
North-West	25	30	32	37	44

CONCLUSION

The investigation carried out has shown, that the model proposed provide for quite an adequate description, at certain distances from the emission source, of the snow cover contamination with PCAH from the sources in Irkutsk city. The dependences obtained allow one also to estimate the total income of PCAH into the areas out of town. For further development of the model, it is important to determine the connections between the processes of local and regional pollution.

ACKNOWLEDGMENTS

The authors express their gratitude to V.Z. Makukhin for his assistance and useful discussions.

This work has been done under financial support from the Russian Foundation for Basic Researches (95–05–15575) and Grant from the SB RAS under the Project (No. 117).

REFERENCES

1. N.L. Byzova, E.K. Garger, and V.N. Ivanov, *Experimental Investigations of Atmospheric Diffusion and Calculations of the Impurity Dispersal* (Gidrometeoizdat, Leningrad, 1991), 297 pp.
2. Ph.T.M. Newnstadt and Ch. van Don, eds., *Atmospheric Turbulence and Simulation of Impurities Dispersal* (Gidrometeoizdat, Leningrad, 1985), 351 pp.
3. *Account for the Dispersal Properties of the Atmosphere when Selecting of the Building Areas for Nuclear Power Plants*, Handbook for NPP-Security, International Agency of Atomic Energy (Vienna, 1980), 106 pp.
4. L.V. Kudryavtzeva and S.N. Ustinova, *Monitoring and Estimation of the State of the Baikal Lake and Nearby Territory* (Gidrometeoizdat, Leningrad, 1991), pp. 86–92.
5. B.E.A. Fisher, Atmos. Envir. **17**, 1865–1880 (1983).
6. V.V. Fedorov, *Theory of Optimal Experiment*, (Nauka, Moscow, 1971), 312 pp.
7. A.N. Tikhonov and A.A. Samarsky, *Equations of Mathematical Physics* (Nauka, Moscow, 1972), 736 pp.
8. *Climate of Irkutsk*, (Gidrometeoizdat, Leningrad, 1981), 247 pp.