FORMATION OF A POLLUTION CAP CLOUD OVER INDUSTRIAL CENTERS

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Based on data of airborne sounding of industrial emissions over Pavlodar, possible concentrations of trace gases are calculated, assuming that they are dispersed in the volume formed by the local air circulation around the city as it follows from the Penenko–Aloyan theory. The comparison of the calculated data with the data of direct measurements at the same altitude has shown good agreement between them that is indicative of the validity of the theoretical statements.

Concentration of industrial facilities on a limited territory, known as a modern city, gives rise to large amounts of different pollutants emitted into the environment, which are not observed under natural conditions. These are various chemical substances in different states and of different origin, extra heat, electromagnetic radiation, and so on. As a result the city becomes "a heat islandB (see Ref. 1). The so-called pollution "capB consisting of gaseous and aerosol species is formed over an industrial center. Its specific feature is that it remains over the city not only at a low wind but also at the wind of mean intensity, disappearing for a short time during the passage of atmospheric fronts, and then the cap reestablishes rather quickly.[2]

The methods developed in Ref. 3, models, and then the calculations, given for the particular regions, have shown[4] that the city is not only the heat island, but the pollution island as well, because of the peculiarities of the local air circulation, occurring in its vicinity. As a result of this circulation, the impurities emitted to the atmosphere over city are blocked within this area by counterblows. This is schematically shown in Fig 1*a*. The diagram is based on the data from Ref. 4 and represents a simplified version of the calculational results.

The data presented in Ref. 4 not only radically alter modern concept of the urban aeration but also give an explanation to a series of facts revealed experimentally which could not be interpreted on the basis of existing models. This is also true for a fast reestablishment (1 or 2 days) of photochemical equilibrium in the atmosphere around an industrial center after the passage of an atmospheric front through the city, cleaning it from contaminants.[2,5]

As far as the author knows, there are no detailed verification of the above calculations. In this case not only the boundary layer must be kept in mind but the entire body of air involved in the local circulation nearby the city. The circulation radius[4] may vary from 50 to 200 km, depending on the size of the industrial center.

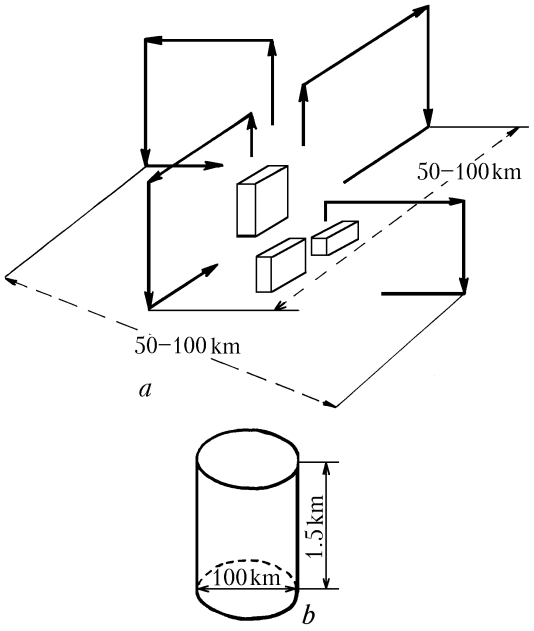

FIG. 1. Diagram explaining formation of the local circulation around the city (a). Diagram of calculated area, considered in this paper (b).

Experience, which has been gained at the Institute of Atmospheric Optics SB RAS on the ecological monitoring of air basin of some cities,[6] enables the compensation for this gap, namely, the calculation of the pollutant concentrations based on the results of direct measurements of the body and composition of industrial emissions and also the comparison of them with the data of direct measurements of the above concentration over cities and in the atmospheric boundary layer. This paper concerns with the above-mentioned problem.

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The city of Pavlodar has been the object of investigation. In spring of 1990 the measurements were performed in Pavlodar of the composition and the amount of emissions of the main industrial sources located on the territory of the city and in the neighboring town Ermak. The main sources and concentrations of different pollutants in the plumes as well as the technique of sampling and methods of analysis are discussed in Ref. 7.

In addition to the measurements of emission parameters in this period, the aerosol pollution concentration was measured in the atmospheric boundary layer on the city territory and at different altitudes over it. 24 samples from the boundary layer were analyzed as well as 27 samples obtained at 200 m height, close to the height of stacks from which smoke plumes were emitted. Assuming that most of the emissions disperse within the region covered by the system of local circulation of air, its parameters are specified as a cylinder 100 km in diameter and 1.5 km in height (Fig. 1*b*). This height coincides with the level of the upper boundary of the mixing layer, determined by the results of vertical sounding.

The table gives the data on the amount of separate aerosol ingredients emitted by the above sources. The amount of emitted substance was determined based on the concentration data measured,[7] and the data on the flow velocity and the cross sectional area of the plume. This table presents the data on the average concentration of the fixed emissions at 200 m height and at the ground surface as well as the concentrations calculated schematically in Fig. 1*b*, assuming that the trace constituents are completely dispersed. The table also gives the concentration ratios calculated from the emission amounts and measured at 200 m height and at the ground surface, respectively.

TABLE. The amount of emission of some aerosol components (t/day) in Pavlodar, their mean concentrations (μg/m^3), *and the ratios.*

Enterprise	Na^+	j $^+$	q l^-	Br^-	p^{5+}	NO_3^-	NH_4^+	SO_4^{2-}	Hg^{2+}	Ag^{5+}	Zn^{2+}
Heat Power Station-1 (HPS)	0.15	0.25	3.87	0.04	0.95	0.02	0.21	0.41	0.02	0.004	0.09
HPS-2	9.70	6.58	10.76	0.08	0.53	0.01	8.24	23.39	0.38	1.96	0.35
HPS-3	0.20	0.11	3.72	0.03	1.28	0.02	2.67	3.34	0.07	1.65	0.01
Aluminum plant	–	0.31	1.42	0.21	0.57	–	1.20	0.09	0.01	0.11	0.03
Tractor plant	0.01	0.01	1.24	0.11	0.14	0.00	0.64	0.42	0.00	0.29	0.01
NPZ	–	1.48	4.28	0.51	0.35	0.03	1.78	0.85	0.11	0.10	0.03
Hydroelectric power plant	2.65	1.38	2.40	2.77	1.90	1.04	7.78	6.95	1.56	1.84	0.16
Mean(calc.)	1.09	0.86	2.35	0.32	0.49	0.09	1.91	2.93	0.18	0.70	0.05
Mean(200 m)	1.50	0.60	2.10	0.70	1.90	0.40	4.60	4.80	0.14	0.90	0.11
Mean(0 m)	2.56	0.97	3.60	0.30	–	0.79	–	0.12	–	0.05	0.03
Calc./200 m	0.73	1.43	1.12	0.46	0.26	0.23	0.42	0.61	1.29	0.78	0.45
Calc./0 m	0.43	0.89	0.65	1.07	–	0.11	–	24.42	–	14.00	1.67

Enterprise	Pb	Cr	Mn	Mg	Zn	Ti	Ca	Si	Fe	V	Al	Cd
HPS-1	0.004	0.09	0.42	0.01	0.26	1.32	1.64	13.15	658	0.01	13.68	2.04
HPS-2	–	0.37	0.22	–	–	1.83	–	18.30	10.25	–	18.69	–
HPS-3	0.02	–	0.02	0.88	0.34	0.79	2.01	19.99	8.03	0.02	12.20	–
Aluminum plant	0.02	0.17	0.27	0.00	0.71	1.30	1.16	9.77	4.46	0.01	8.46	1.44
Tractor plant	–	0.08	0.02	0.06	0.03	0.08	0.31	4.64	0.71	–	2.50	–
NPZ	–	0.43	0.04	0.01	0.00	0.41	5.51	23.09	12.31	0.00	23.60	4.00
Hydroelectric power plant	0.01	1.73	0.35	0.81	1.35	2.77	8.82	32.64	17.99	0.03	38.06	5.88
Mean(calc.)	0.005	0.24	0.11	0.15	0.23	0.72	1.65	10.32	5.12	0.006	9.95	1.13
Mean(200 m)	<	0.41	0.29	3.50	0.10	0.20	0.80	6.10	3.10	0.015	6.20	0.90
Mean(0 m)	0.02	0.02	–	0.06	0.05	0.03	0.32	0.27	0.46	–	5.70	–
Calc./200 m	–	0.59	0.38	0.04	2.30	3.60	2.06	1.69	1.65	0.40	0.60	1.25
Calc./0 m	0.25	12.00	–	2.50	4.60	24.00	5.16	38.22	11.13	–	1.75	–

The table shows that at 200 m height the concentration ratio calculated on the basis of the total emission of the main sources and measured outside the plumes is close to unity in the majority of cases, varying from 0.23 to 1.69 except for Mg (0.04), Zn (2.30), Ti (3.60), Ca (2.06). It is quite probable that the Mg source is of different type, and Zn, Ti, Ca are constituents of giant particles, which quickly

precipitate. Such an agreement of calculated and measured concentrations (19 from 23 components studied) in the air of a particular town is indicative of the validity of the results obtained using the methods from Refs. 3 and 4, since the concentrations turned out to be close in values, within the errors of determination of the aerosol chemical composition, given in Ref. 7.

The bottom line in the table shows the concentration ratio, calculated based on the emission amount of the main sources and measured in the atmospheric boundary layer, that enables one to estimate the contribution of the sources that emit at high altitudes. It should be noted that in the city there is one more large source of pollutants, namely, motor transport, whose emissions come directly to the atmospheric boundary layer.

It is evident from the analysis of the data on the ratio of concentrations of emissions at a height and at the ground surface that the concentrations of Na^+, K^+, Cl^-, NO_3^- are larger in the atmospheric boundary layer that shows the action of the sources located below. The concentrations of metals, Cr, Ti, Ca, Si, Fe, and ions of SO_4 and As are much less than the calculated ones. This obviously points to the fact that these pollutants do not enter directly the boundary layer but are dispersed over the entire area, given in Fig. 1*b*.

Thus the results of complex determination of the anthropogenic aerosol dispersal in the air over Pavlodar and in the vicinity of the city clearly show that the theoretical approach[3] and the results of numerical simulations[4] describe reliably the local air circulation in the vicinity of Pavlodar, which results in the formation of the "island of pollutantsB over its territory.

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