INDUSTRIAL ECOLOGY

© LARISA V. STAVNIKOVA[1], ROBERT A. STEPEN'[2]

[1]Post-graduate Student
Department of Industrial Ecology, Processes and Facilities of Chemical Industry,
Siberian State Technological University (Krasnoyarsk)

[2]Dr. Biol. Sci., Professor
Department of Industrial Ecology, Processes and Facilities of Chemical Industry
Siberian State Technological University (Krasnoyarsk)

hlorka26@rambler.ru

UDC 504.51.6

ENVIRONMENTAL RISK ASSESSMENT OF INDUSTRIAL AND MOTOR VEHICLE EMISSIONS (the case of Krasnoyarsk)

SUMMARY. The transformation of Krasnoyarsk economy from wood chemistry to metal-smelting and construction and rapid motorization have seriously changed its environmental situation. The study of its state has been based on official environmental documents, pollution of atmosphere and a complex of bioindicative methods. The data indicate a two-fold reduction of aerogenic load since the 1990s in comparison with the end of the 1990s and the beginning of the 2000s (from 370 to 180 thousand tons). Having started in 2002, the increase of production and the growth of motor vehicles led to the fact that in 2010 it was only slightly (280 thousand tons) inferior to the pre-perestroika period and remains practically stable. Pollution dynamics has become characterized by the increase of vehicle emissions harmful effects share in the total pollution of the city. Despite the 3.5-fold exceedance of potential aggressiveness of pollutants from stationary sources, motor vehicle emissions due to their low emission are more dangerous for the population. The value of APS_5 (Air Pollution Source) of the industrial Sovietsky and Leninsky districts is less than its value in the settlement Central district with its powerful motorways. Research results indicate excess hazard motor vehicle emissions over stationary sources emissions.

KEY WORDS. Transport, industrial pollution, emission, toxicity of pollutants.

The toxicity of emissions of Krasnoyarsk mobile and stationary sources of pollution has been calculated. It is shown that motor transport emissions are more dangerous to health.

It is believed that the negative effects of air pollution in Siberia increase from motor transport to industrial plants and thermal power plants. The quantitative aspect of the question is without doubt because thermal power plants use brown coal with high content of ash dust. However such research requires taking into account economic changes, especially reorientation and rapid motorization. Other important factors are admixtures scattering efficiency and components toxicity. This question is relevant for Krasnoyarsk-city (with a million plus population) which is one of the most polluted cities in the country [1].

The research objective is to compare the weight and the harmful impact of industrial and motor transport emissions of urban pollution sources on Krasnoyarsk population.

The direct consequence of the economic reorientation in the years of perestroika in Krasnoyarsk was the change of urban atmospheric emissions content and, as a result, increased number of diseases among population [2]. Examination of the air condition in the regional center in 1992-2009 was carried out by studying the materials of state reports on the environment status and management, motor vehicles load data and chemical and bioindicative analyses results. Atmospheric air pollution form was calculated according to motorways load on the basis of vehicles types per time unit [3]. During bioindicative research the environment condition was visually evaluated and fir-needles were analyzed by means of standard morphometric, gravimetric and biochemical methods [4].

The biological object was Siberian spruce growing in the urban environment and forests. The experiments were devoted to the results of three-year-old fir-needles analyses. The main research was conducted with needles from the tree plots in the Leninsky district. Twigs were collected from the middle part of the trees growing in the same soil and climatic conditions and distant about 800 m from each other. The first plot, "industrial", was near the chemical plant "Yenisei" exposed mainly to this enterprise emission, Yenisei Pulp and Paper Plant and Thermal Power Plant-1. The second plot (№ 2) is located near the most powerful motorway of the Right Bank – Krasnoyarsk Worker Avenue. It is subjected to vehicle emissions. In the Soviet district a similar motor vehicle impact and significantly less industrial impact are experienced by trees growing respectively near the edge of the motorway (№ 3) and inside (№ 4) Guards' Park. The plot near Rybnoye village of the Ilan District, the Krasnoyarsk region, (№ 5) was taken as a control plot.

Trees condition and size, needles color, bloom and chlorosis presence on them were visually evaluated in the plots. For analysis a twig was selected from each tree. Under laboratory conditions fir-needles were picked from twigs, they were averaged and the resulting samples were analyzed in a 2-3-fold replication. Humidity and weight were estimated, essential oil and pigment were studied in the samples. Content and composition of chlorophylls and carotenoids were analyzed photometrically; essential oil egress – volumetrically, its composition – by gas-liquid chromatography using the stationary phase SE-30 at Chromaton A and flame ionization detector [5]. Oil content and fractional composition changing under the influence of pollution enables to quantify the environmental situation in the area [4].

In the past 20 years restructuring, transfer of Krasnoyarsk economy from wood chemistry to metal-smelting and construction has led to major changes in aerogenic pollution of the city including quantitative and component composition of emissions. Very high emissions in the early 1990s coming from the use of worn-out equipment lowered in the late 1990s due to the decline in productivity and the elimination of a number of enterprises. Production increase and industrial development which is clearly seen due to the increase in the number and intensity of motor vehicles operation, has led to aerogenic load gain since 2002. In 1993 it ran to 374 thousand tons, in 2002-2003 went down to 190-200 thousand tons and by 2006-2009 it increased again to 270-280 thousand tons. An important aspect of air pollution intensification in the 1990s was emphasis on the reduction of production costs at the expense of the disregard of the environment. It further worsened the environmental situation in industrial Lenin and Soviet districts.

Dynamics of industrial and road transport emissions varies considerably. Weight of pollution by motor vehicles with rare exceptions (1998 and 2002) in the period 1992-2005 was practically at the same level (about 55 thousand tons /year) and in 2006 it almost doubled. At the same time, industrial-energy emissions amounts as well as the total amount of pollution were characterized by steady decline in the 2000s, rise in 2004-2005 and a further notable reduction. The main reason for similar emissions from mobile sources in the 1990s and 2000s was a serious economic recession with simultaneous transfer of transport from legal bodies to individuals contributing to their increased exploitation. Its subsequent increase was due to the production increase. But dynamics of industrial-power emissions is associated with consistent deteriorating of the city's economy that reached its minimum in the early 2000s. Then it was replaced by short-lived boom in 2004-2005 and subsequent stagnation. It should be noted that the proportion of the contribution of the main pollution sources (Krasnoyarsk Aluminum Plant and Thermal Power Plant) among 11 major stationary enterprises of Krasnoyarsk region (0,43-0,44 %) and the city (0,75-0,78 %) during the research remained close, while compared to the total emissions of Krasnoyarsk decreased significantly (1996 — 0.62 2001 — 0.52 and 2009 — 0.43). Logical explanation for this is a substantial production technology upgrade and the growth in the number of vehicles.

Air toxicity is measured by the composition of extraneous substances in it and is expressed by environment pollution index. In Krasnoyarsk it is presented by four permanent compounds — benzapyrene, formaldehyde, suspended particulate matter and nitrogen dioxide. In the analyzed period, the toxicity was always determined mainly by the contribution of the first of them – from 70-75 % in the late 1990s, to 30-40% in the 2000s and 50-55 % in recent years [6]. There is a significant increase in the contribution of formaldehyde: from 5-6 % in the initial period up to 15-25 % in the remaining years. Aerogenic pollutants weight and composition dynamics character, taking into consideration the constant improvement of Krasnoyarsk Aluminum Plant technologies, indicates a transition in the process of emissions type transformation – from stationary to mobile sources. Such an idea is more clearly

proved by the comparison of variability of Air Pollution Source 5 in the industrial Soviet and the residential Central districts. At first its value ranges within 10-13 units in the last 10 years, in the second – it increased from 11 units in 2002 to 24 units in 2008, significantly exceeding the citywide.

Taking into consideration motor transport ownership, the amount of kilometres travelled by its different categories in the urban environment and the assumption that emissions are made by passenger carburetor cars and an equal amount of gasoline and diesel lorries and buses, the weight of the major components of emissions in 2007 was calculated for Krasnoyarsk vehicle fleet [7]. The results were close to the official data [6]. The calculations show that the vehicle fleet emissions polluted the atmosphere of the city, thousand tons: carbon monoxide — 108.8, nitrogen dioxide — 14.6, hydrocarbons — 20.5, sulfur dioxide — 1.4, formaldehyde — 0.24, lead derivatives — 0.06, benzapyrene — 13.9 kg. By transport categories emissions amounted to, tons per year: passenger cars — 39.6, lorries — 92.3 and buses — 14.8. Stationary sources emissions weight was taken from public report materials on Krasnoyarsk environment state and management [6].

Known components' weight enables to roughly calculate and compare the aggressiveness of motor vehicles and industrial-energy emissions (Table 1).

Table 1

The potential aggressiveness of mobile and stationary emissions, 10 rel. units[9]

Components	emissions		Components	Emissions	
	Motor vehicles	Industrial		Motor vehicles	Industrial
Carbon monoxide	108,8	83,0	Fluorine compounds	-	222,3
Nitrogen dioxide	600,1	637,1	Cuprum and its derivatives	-	0,1
Hydrocarbon	293,2	-	Nickel and its derivatives	-	0,1
Sulfur oxides	35,8	716,8	Toluene	-	0,1
Formaldehyde	81,6	4,7	Hydrogen sulphide	-	0,1
Lead derivatives	204,6	0,1	Ammonia	-	0,1
Benzapyrene	27,8	228,6	Chlorine	-	0,1
Soot	27	686,0	Total	1353,8	4638,6

The calculations show that the aggressiveness of industrial-energy emissions is 3.5 times higher than that of motor transport. However, the latter case does not take into consideration the contribution of dust and dioxins, the first case — volatile organic compounds. In both types of emission its cumulative large-tonnage components are

nitrogen oxides; significant additional — in mobile sources — hydrocarbons, lead derivatives and carbon monoxide, in stationary — sulfur oxides, soot, benzapyrene and fluorine compounds.

However, the excess of potential aggressiveness of industrial-energy emissions over the motor vehicle ones cannot be considered sufficient to make a conclusion about the prevalence of harmful effects of stationary over mobile sources for the population. Along with pollutants weight and aggressiveness, impurities toxity is not less determined by the level of their dispersion, which in the latter case is 40-60 times lower [8].

The conclusion about the toxicity of emission type was made on the basis of official materials analysis and the obtained experimental data. In the first case API_5 (Air Pollution Index) values were compared in the Soviet district where the main city enterprises (Krasnoyarsk Aluminum Plant, Krasnoyarsk Metallurgical Plant, etc.) are, and the Central where they are virtually absent. Significant pollution excess in the Central (API_5 21-24) compared to the Soviet district (API_5 11-13) indicates a more serious negative impact of motor vehicle emissions over industrial ones.

In order to directly assess the impact of compared emissions on living organisms bioindicative research was conducted on spruce plantings growing on closely spaced plots, under the influence of motor (№ 2) and industrial (№ 1) emissions. The inspection shows that the state of trees on both plots is practically the same, although there is less third-year needle on the latter than on the first. Moreover, here it is lighter and there are more blooms and chloroses on it, which is a sign of regression development. Its morphometric parameters in the plot № 2 are slightly smaller than in the first (the length is 15.3 and 16.5 mm, and the volume is 10.6 and 12.9 mm^3). The needles of both plots are noticeably inferior to the needles of park (10-15%) and forestry (18-23%) plantings.

In the biochemical more informative research in addition to the needles of plots 1 and 2 spruce needles were analyzed in the Soviet district: № 3 — 5 metres from the motorway and № 4 — in the depths of the park. The results of the analysis and calculations of the pigment composition are shown in Table. 2.

Table 2

Influence of air pollution on the content (mg/g) and the structure of pigments

Plots	Chlorophyll a	Chlorophyll b	Chlorophylls ratio, type a/ b	Chlorophylls sum, a+ b	Carotenoids , k	Pigments ratio, (a+ b)/k
1	707±11	255±8	2,73	962	296±8	3,25
2	694±9	243±10	2,96	937	292±7	3,21
3	688±11	224±7	3,07	912	288±8	3,25
4	758±14	279±10	2,72	1039	301±10	3,45
5	934±12	326±8	2,87	1260	346±10	3,64

The content of chlorophylls a and b and carotenoids, as well as the ratio of the sum of the first to the latter sequentially decreases from the control (№ 5) to the park (№ 4) plots and plantings that are under the influence of industrial (№ 1) and motor vehicle (№ № 2 and 3) emissions. The ratio of chlorophyll types to each other changes in the opposite direction. The established regularity of contribution and pigments ratio, according to the literature data [9, 10], indicates increased risk of motor transport emissions compared to industrial ones.

The same conclusions were obtained in the study of the fractional composition and the contribution of spruce essential oil of the researched plots (Table 3).

Table 3

Yield and composition of spruce essential oil on the plots of varying intensity of aerogenic pollution

Indices	Plots				
	1	2	3	4	5
Yield, %	0,68	0,61	0,64	1,01	0,89
The ratio of monoterpene hydrocarbons to the sum of oxygenates and oil sesquiterpenoids	0,81	0,68	0,71	1,32	1,71

The ratio of light and heavy fractions, as well as the content of essential oil, characterizes the sequential increase of environmental load, the rate of terpenoids conversion under the influence of pollution [11]. In accordance with the developed classification [4] on environmental criteria spruces on plots № № 1,2 and 3 have been referred to the fourth, № 4 – to the second № 5 – to the first type. Seeming illogical increased oil content in spruce needles on plot № 4 is explained by the stimulation of these compounds synthesis with average air pollution as a plant response to the negative impact of the environment.

The research has calculated the toxicity of motor transport and industrial-energy emissions of Krasnoyarsk. The analysis of official materials and bioindicative research data has shown that emissions from mobile sources having a much lower weight compared to the industrial emissions due to their low level of emission from the source have a much more negative impact.

REFERENCES

1. Frumin, G.T. Air Pollution in Major Cities of Russia and Health Risk. *Jekologicheskaja himija — Environmental Chemistry*. 2002. № 11 (2). Pp. 73-77. (in Russian).

2. Idimichev, V.F. Environmental State of Krasnoyarsk and Problems of its Improvement // *Strategija social'no-jekonomicheskogo razvitija Krasnojarska do 2010 goda* [Strategy for Socio-Economic Development of Krasnoyarsk up to 2010]. Krasnoyarsk, 2004. Pp. 243-245. (in Russian).

3. Fedorova, A.I., Nikol'skaja, A.N. *Praktikum po jekologii i ohrane okruzhajushhej sredy* [Laboratory Manual on Ecology and Environmental Protection]. Moscow, 2006. 277 p. (in Russian).

4. Esjakova, O.A., Stepen', R.A. *Zonirovanie zagrjaznenija atmosfery g. Krasnojarska bioindikacionnymi metodami* [Zoning of Krasnoyarsk Air Pollution by Bioindicative Methods]. Krasnoyarsk, 2011. 124 p. (in Russian).

5. Ushanova, V.M., Lebedeva, O.I., Devjatlovskaja, A.N. *Osnovy nauchnyh issledovanij. Ch. 3. Issledovanie himicheskogo sostava rastitel'nogo syr'ja* [Foundations of Scientific Research. Part 3. Study of Plant Raw Materials Chemical Composition]. Krasnoyarsk, 2004. 360 p. (in Russian).

6. *Gosudarstvennye doklady «Osostojanii i ohrane okruzhajushhej sredy v Krasnojarskom krae»* [State Reports «On the Environment State and Protection in Krasnoyarsk Krai»]. Krasnoyarsk, 1993-2009. (in Russian).

7. *Metodicheskie posobija po vypolneniju svodnyh raschetov zagrjaznenija atmosfernogo vozduha vybrosami promyshlennyh predprijatij i avtotransportom gorodov (regionov)i ih primenenie pri normirovanii vybrosov* [Manuals for the Implementation of Summary Calculations of Air Pollution by Emissions from Factories and Vehicles of Cities (Regions) and their Use in the Emissions Regulation]. St.-Petersburg, 2000. 320 p. (in Russian).

8. Lobanov, A.I., Stepen', R.A. *Vozdejstvie avtotransportnyh vybrosov na okruzhajushhuju sredu g. Krasnojarska* [Impact of Motor Vehicle Emissions on the Environment of Krasnoyarsk]. Krasnoyarsk, 2005. 120 p. (in Russian).

9. Neverova, O.A., Candekova, O.L. Photosynthetic Ability of Woody Plants as an Indicator of the Cumulative Air Pollution of the Urban Environment. *Sibirskij jekologicheskij zhurnal — Siberian Journal of Ecology*. 2010. V. 17. № 2. Pp. 193-196. (in Russian).

10. Tuzhilkina, V.V., Ladanova, N.V., Pljusnina, S.M. Influence of Anthropogenic Pollution on the Photosynthetic Apparatus of Pines. *Jekologija — Ecology*. 1998. № 2. Pp. 89-93. (in Russian).

11. Esjakova, O.A. Evaluation of Air Pollution on the Composition of Krasnoyarsk Siberian Spruce Assimilation Apparatus. *Vestnik Krasnojarskogo gosudarstvennogo agrarnogo universiteta — Bulletin of Krasnoyarsk State Agrarian University*. 2009. № 4. P. 89-93.(in Russian).