UDC 502.7:631.46

Chemical Trace of Emissions from Aluminum Production (Soil Ecology Aspect)

E. V. NAPRASNIKOVA

Sochava Institute of Geography, Siberian Branch of the Russian Academy of Sciences, Ul. Ulanbatorskaya 1, Irkutsk 664033 (Russia)

E-mail: napev@irigs.irk.ru

(Received December 12, 2012)

Abstract

Studies were performed concerning the features of soil ecological, microbiological and biochemical properties under influenced by the emissions of aluminum plants in Siberia. It has been found that the anthropogenically transformed soils of sub-taiga influenced by water-soluble fluoride species (10–20 MPC) cause the greatest inhibition of actinomycetes and chemoorganotrophic asporogenous bacteria. The steppe chernozem under the influence of fluorine (1–4 MPC) demonstrates a decrease in the level of biochemical activity.

Key words: soil cover, aerotechnogenic emissions, microorganisms, biochemical activity

INTRODUCTION

Humankind connects the hopes for survival not only with a clean atmosphere and high water quality, but also with the conditions of soil and vegetation. As it is known, the soil represents a core of the urban system and provides its purification, the neutralization of hazardous compounds, the safety of greenery. In addition, the condition of urban soils is an indicator of the living conditions and the health of the population. This implies the urgency of studying the ecological condition of soils exposed to profound chemical attacking by the emission of aluminum production enterprises. Under the conditions of the vulnerable Siberian nature, this problem looks much more acute, especially when taking into account that the concept of sustainable development implies a dynamic equilibrium in the socio-ecosystems of different levels.

The aim of this study consisted in assessing the influence of profound man-caused pollution by the aluminum industry upon microorganisms and the biochemical activity of soils under the conditions of sub-taiga and steppe landscapes of Siberia.

OBJECTS AND METHODS

The objects of the detailed study were presented by urban soil in the cities (Shelekhov, Sayanogorsk) and adjacent areas within the emission impact zone of aluminum production enterprises in Irkutsk (IrkAZ-RUSAL JSC) and in Sayanogorsk (SAZ), respectively.

The Shelekhov city is located in the south of the Irkutsk–Cheremkhovo plain 20 km southwest from Irkutsk. According to [1], in the impact zone of the IrkAZ there are anthropogenically transformed soils dominated with a low humus horizon. The content of water-soluble fluorine species in these soils is high being at a level of 10–20 MPC (0–10 cm layer). With increasing the distance from the plant, the fluorine content exhibits a decrease. In 2000, the city has been included in the priority list of

© Naprasnikova E. V., 2013

Russian cities with the highest levels of air pollution. The latter is promoted by the location in a valley, wherefrom it is very difficult to remove airborne industrial emissions. In the atmosphere over the IrkAZ there were found about 200 compounds including benzo(a)pyrene, formaldehyde, chlorine, methane, carbon dioxide, nitrogen, hydrogen fluoride, solid fluorides, silicon oxides [2].

The Sayanogorsk city is located in the southern part of the Minusinsk depression of the Krasnoyarsk Territory, 16 km from the SAZ. The soil cover within the impact zone of the plant is presented by low-humus southern chernozem species. The thickness of the soil profile is equal to 30–40 cm. According to [3], the specific elements of the SAZ emissions polluting the soil solutions are presented by fluorine and sodium. The content of water-soluble fluorine in soils of the impact zone of the SAZ dust and gas emissions ranges within 1–4 MPC.

The soil cover of the territories under investigation is located within a module of constant man-caused pollution that penetrates

TABLE 1

Number of microorganisms in the soil cover of the cities under study and adjacent areas, million CFU/g of soil

Sampling points	Chemoorganotrophic eubacteria	Actinomycetes assimilating mineral nitrogen sources		Micromycetes	Mineralization coefficient
Shelekhov					
			Residential zone		
1	0.43	0.65	0.06	0.001	1.51
2	0.94	0.30	0.01	0.06	0.32
3	0.30	0.60	0.03	0.08	2.0
4	0.81	0.62	0.04	0.004	0.76
5*	0.52	1.4	0.06	0.005	2.70
			Industrial zone		
6	0.18	2.3	0.005	0.05	12.7
7	0.07	0.66	0.002	0.006	12.0
			Agricultural zone		
8	0.58	1.20	0.3	0.07	2.1
9	0.80	1.50	0.4	0.08	1.87
			Control (sod forest soil)		
10	2.1	1.30	0.79	0.08	0.62
Sayanogorsk					
			Residential zone		
1	3.0	2.5	0.20	0.06	0.83
2	2.8	0.7	0.30	0.02	0.25
3*	3.4	2.6	0.33	0.03	0.77
			Industrial zone		
4	0.7	0.3	0.08	0.01	0.43
5	0.1	0.12	0.06	0.01	1.2
			Recreational zone		
6	2.6	3.5	0.30	0.02	1.34
7	3.0	1.7	0.24	0.01	0.56
			Control (chernozem leached on calcareous alluvium)		
8	3.2	2.5	0.40	0.07	0.78

*Private sector.

over large areas. These soils are considered as technogenically polluted ones.

The sampling of soil for the analysis was carried out from the areas of 25 m^2, from the depth of 0–10 cm according to methodological guidelines [4]. From 10–15 individual samples we prepared a mixed sample (in the case of urban soil we removed debris and other inclusions). The sanitary and microbiological evaluation was performed by means of standard methods [5]. The determination of biochemical activity of soil (BAS) was performed using an express method presented in [6]. The essence of this method consists in determining the rate (in hours) of changing the pH value depending on the amount of ammonia evolved in the decomposition of carbamide. The smaller the number of hours, reflecting the reaction rate, the higher is the level of BAS. This integral component was not chosen selected occasionally. It is known that the BAS parameter is an informative indicator of the soil functional capability at the current time being controlled by environmental factors. The pH values were registered by means of potentiometric method.

RESULTS AND DISCUSSION

The studies have demonstrated that the amount of ammonifying eubacteria in the Shelekhov soil cover ranges from 0.3 to 0.94 million CFU/g of soil for the residential area. Much smaller amount thereof was revealed in the soils of industrial zone (from 0.07 to 0.18 million CFU/g); in the case of the control zonal soil the number of this group amounts up to 2.1 million CFU/g (Table 1). There is an inhibition effect observed for the number ammonifying chemoorganotrophic bacteria under the influence of a priority pollutant such as hydrogen fluoride, even for the soils of the residential area, wherein adding a great amount of the organic substances of human origin is inherent. The qualitative composition of chemoorganotrophic eubacteria is presented mainly bacilli and pseudomonads. Coccoid species exhibit a rare occurrence. These data indicate a poor biodiversity of the bacterial component. Actinomycetes, as it has been revealed, are the most sensitive with respect to the airborne industrial emissions of the IrkAZ (see Table 1); the number thereof in the soil of residential areas ranges from 0.01 to 0.06 million CFU/g being significantly lower than the corresponding value for the control zone, wherein we revealed 0.79 million CFU/g of soil.

In the soil of the industrial zone, the number of the mentioned group is an order of magnitude smaller to indicate a high sensitivity of his group with respect to the effects of man-caused emissions. The biodiversity of actinomycetes is low, being presented by genus *Streptomyces*, sections *Albus* and *Cinereus*. The number of micromycetes is low, too, but the variety is much greater as compared to actinomycetes. The soil cover of the Shelekhov exhibit the domination of microscopic fungi tolerant to neutral and slightly alkaline pH values belonging to genera such as *Aspergillus*, *Penicillium*, *Trichoderma*, *Cladosporium*, *Scopulariopsis*. At the same time, in the zone soil (control sample), alongside with the mentioned genera, there have been other genera found, such as *Curvularia*, *Verticilium*, *Alternaria*, *Mycogone, Fusarium*, *Mucor*.

In this work, we investigated quantitative and qualitative composition inherent in the sanitary indicative bacteria (coliform bacteria) in soils. From Table 2 one can see that the titre of the coliform bacteria did not exceed 0.1 for the residential areas, whereas the coli index (the number of coliform bacteria in 1 g of soil) ranged within 20–35. Within the industrial zone, there were no coliform bacteria detected. Consequently, one could assess the soil cover of the Shelekhov to be clean and slightly polluted. We associate this not only with a high sanitary culture or a high level of sanitary measures, and even not with the self-purification properties of the soils, but also with the inhibiting action of the priority pollutants inherent in aluminum plant emissions, such as fluorides (10–20 MPC).

The results of similar studies in Sayanogorsk (see Table 2) demonstrated that the number of ammonifying eubacteria is significantly higher as compared with that in the soil cover of the Shelekhov city. The soils of the Sayanogorsk residential area, just as those of the recreational zone, are characterized by a high number of ammonifying bacteria. In the soils of the industrial zone, the number ammonifying eu-

TABLE 2

Sanitary and microbiological evaluation of soil in the cities under investigation and adjacent areas

Sampling points	Coliforms		Content of sanitary indicative bacterial types, %			Evaluation of soil sanitary condition
	Titre	Titre	*E. coli*	*Ent. aerogenes*	*C. freundii*	
Shelekhov						
			Residential zone			
1	0.1	20.0	10	40	60	Slightly polluted
2	0.1	20.0	0	30	70	» »
3	0.1	30.0	10	30	60	» »
4	0.1	35.0	0	40	60	» »
5*	0.1	50.0	10	40	50	» »
			Industrial zone			
6	n/d	n/d	0	0	0	Clean
7	n/d	n/d	0	0	0	»
			Agricultural zone			
8	n/d	n/d	0	0	0	»
9	n/d	n/d	0	0	0	»
			Control (sod forest soil)			
10	n/d	n/d	0	0	0	»
Sayanogorsk						
			Residential zone			
1	0.001	135.0	10	30	60	Moderately polluted
2	0.01	27.0	10	20	70	Slightly polluted
3*	0.0001	900	15	20	65	Severely polluted
			Industrial zone			
4	0.1	38.0	0	20	80	Slightly polluted
5	0.1	24.0	0	20	80	» »
			Recreational zone			
6	0.001	140	15	30	55	Moderately polluted
7	0.001	320	10	25	65	» »
			Control (chernozem leached on calcareous alluvium)			
8	n/d	n/d	0	0	0	Clean

Note. n/d – not detected.

* Private sector.

bacteria is extremely small. The qualitative composition of the bacteria is similar, since it is mainly presented by the bacilli and pseudomonads. The number of bacteria assimilating mineral nitrogen sources is slightly higher for soils of the Sayanogorsk, which is consistent with the features of the soil conditions of the steppe landscape for this group of microorganisms. The number of actinomycetes is there an order of magnitude higher as compared to that of the Shelekhov soil, which corresponds to the general laws of the ecological and geographical distribution thereof. The qualitative composition of this group is much more diverse. In addition to sections *Albus* and *Cinereus*, there are the representatives of section *Roseus* present. The qualitative composition of micromycetes in the soil cover is relatively diverse. To micromycetes dominant in the soils of the Shelekhov, there should be *Spicaria* and *Rhizopus* added.

The composition of sanitary indicative bacteria (coliforms) in soils of the Sayanogorsk and adjacent areas is presented in Table 2. All the

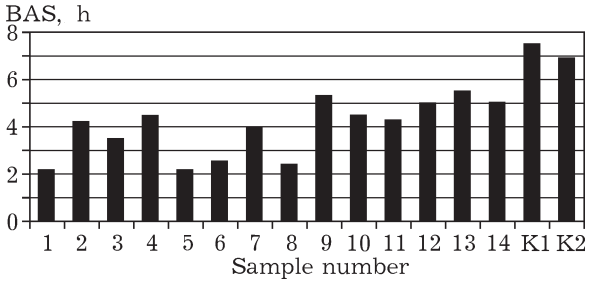

Fig. 1. Biochemical activity of soils (BAS) in different functional areas of the Shelekhov city and adjacent territories: 1–8 – residential zone; 9–11 – recreation zone; 12–14 – industrial zone; K1, K2 – control.

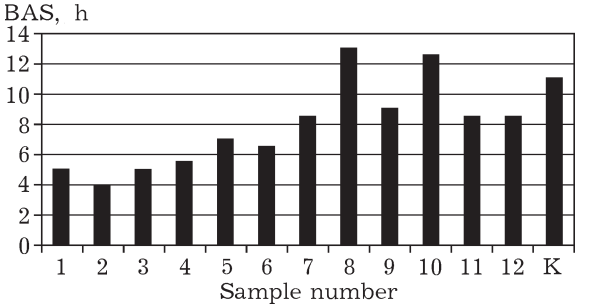

Fig. 2. Biochemical activity of soils (BAS) in different functional areas of the Sayanogorsk city and adjacent territories: 1–6 – residential zone; 7–11 – industrial zone; 12 – recreation zone; K – control.

figures indicate soil contamination in the sanitary point of view. The titre and index of the coliforms varies to a considerable extent depending on the sampling location. So, *Escherichia coli* was found in all the functional areas of the city, except for the industrial zone. The sanitary condition of the soils under investigation was estimated from the contamination level from weak to moderate. The comparative analysis of the sanitary indicators of the cities allows one to conclude that the soil inherent in the Sayanogorsk is much more contaminated. This fact could be associated with the specific soil cover of the Minusinsk steppe, including soil pH (neutral and alkaline) and the transformation of SAZ emissions elements within the range of 1–4 MPC.

It is known that the BAS value is one of most informative indicators concerning the functional capabilities of soil at the current moment of time, which value is determined by the environmental factors, particularly the acidity conditions (pH). In this regard, we applied an express method [6] that has received a wide approbation to be valuable, especially in the studies concerning urban and industrial areas [7].

The character of changing the BAS value is presented in the form of graphs (Figs. 1, 2). It should be noted that the biochemical potential of soil as an indicator of the current ecological status and self-purification ability thereof is worthy special attention because this parameter represents an integral and highly informative value. In other words, the BAS represents a multifunctional parameter that is directly dependent on environmental factors, including man-caused ones.

For the soil samples inherent in the Shelekhov (see Fig. 1) within the framework of the laboratory-scale investigations we revealed two sets of data whereby one could distinguish the groups of soils according to the activity level thereof: from 2 to 5 h for the group I , 5 h or more for the group II. The greater is the number of hours that reflects the rate of urea decomposition, the lower is the activity level of the soil under investigation. Within the residential area, the activity is greater as to compare with the control, which is typical of urban soils. This fact cannot be considered positive, because a significant increase in the BAS could result in the loss of nutrient element such as nitrogen. Within the recreational and industrial areas the activity level of the soil is somewhat less and being close to the values inherent in the control sample. As far as the soil samples from the Sayanogorsk (see Fig. 2) are concerned, one could divide them into two groups of soil according the activity level thereof: from 4 to 7 h for the group I, and 8 h or more for the group II.

There is a similarity between the indices of BAS for the residential sphere of both cities, whereas the soils of industrial areas exhibit lower values compared to the control samples.

CONCLUSION

The studies have demonstrated that in the case of the Shelekhov city, where the soil cover undergoes a maximum aerotechnogenic load, the greatest inhibition is experienced by actinomycetes and chemoorganotrophic asporoge-

nous bacteria. For the first there has been experimentally revealed a chemical trace of fluoride inhibitory effect (10–20 MPC) that is observed particularly for the sanitary and microbiological indicators of the Shelekhov soil.

The condition of the Sayanogorsk soil according to these indicators has been assessed to be unfavourable. At the Sayanogorsk there occurs a less inhibition of coliform bacteria under the influence of fluoride (1–4 MPC). In this connection, the sanitary condition of the soil cover in Sayanogorsk requires for particular attention and special sanitation measures. For example, sowing perennial grass, first of all, legumes on the lawns, waysides, intra-yard space could significantly reduce the amount of coliform bacteria to improve the overall sanitary status of urban soils.

As compared to the control in the industrial area of cities and adjacent territories, one can observe a tendency of reducing the biochemical activity of the soil related to the nitrogen cycle, against the background of decreasing the number of ammonifying microorganisms.

The results of the study performed demonstrate the potentiality of using indicative biochemical and microbiological parameters for the environmental monitoring the soil under the conditions of potentially hazardous aerotechnogenic industrial emissions connected with aluminum production.

REFERENCES

1 Belozertseva I. A., Matushkina O. A., in: Sovremennye Problemy Baikalovedeniya (Treatises), Izd-vo IrGU, Irkutsk, 2001, pp. 19–29.
2 Gosudarstvenny Doklad o Sostoyanii Okruzhayushchey Prirodnoy Sredy Irkutskoy Oblasti, Irkutsk, 2010.
3 Davydova N. D., Geograficheskiye Issledovaniya v Sibiri, Novosibirsk, GEO, 2007, vol. 2, pp. 261–276.
4 GOST 17.4.02–84. Okhrana Prirody. Pochvy. Obshchiye Trebovaniya k Otboru Prob, Izd-vo Standartov, Moscow, 1984, p. 4.
5 Zvyagintsev G. D. (Ed.), Metody Pochvennoy Mikrobiologii i Biokhimii, Izd-vo MGU, Moscow, 1991.
6 Aristovskaya T. V., *Pochvoved.*, 11 (1989) 142.
7 Naprasnikova E. V., *Pochvoved.*, 11 (2005) 1345.