Toxic trace elements in solid airborne particles and ecological risk assessment in the vicinity of local boiler house plants

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ABSTRACT

The article deals with assessment of anthropogenic pollution in vicinity of local boilers using the data on microelement composition of solid airborne particles deposited in snow. The anthropogenic feature of elevated accumulation levels of solid airborne particles deposited in snow in the vicinity of coal-fired boiler house is revealed in elevated concentrations (3-25 higher than background) of Cd, Sb, Mo, Pb, Sr, Ba, Ni, Mo, Zn and Co. In the vicinity oil-fired boiler house the specific elements as parts of solid airborne particles deposited in snow are V, Ni and Sb, as their content exceeds the background from 3 to 8 times. It is determined that the maximum shares in non-carcinogenic human health risk from chronic inhalation of trace elements to the human body in the vicinity of coal-fired boiler house belong to Al, Mn, Cu, Ba, Co, Pb, whereas in the vicinity of oil-fired boiler house – Al, Mn, Cu, Ni, V.

Keywords: boiler-house plant, snow cover, solid airborne particles, trace elements, environment risk assessment

1. INTRODUCTION

Particulate matter (PM) is solid or liquid particles suspended in the Earth's atmosphere. Anthropogenic sources of particulate matter are fuel combustion in car engines and fossil fuel combustion by thermal and industrial plants [1-3]. As thermal facilities operating on coal take the first place in the amount of solid particle emissions and those using liquid fuels take the second place, the urgent issue is to study sizes and composition of released particles [4]. Fine and ultra-fine particles formed in fossil fuel combustion can have a negative effect on cardio-vascular system [5].

In winter the amount of burnt fuel achieves its maximum and, as a result of wet and dry deposition, released solid particles settle on the snow cover, which results in certain anthropogenic load in the residential areas located close to thermal facilities and poses a risk for human health. Snow is one of the most informative indicators to assess the air pollution of a site, which has been shown by the authors [6-9] as well as our researchers [10-12]. The relevance of such studies increases if they are added with assessment of ecological-hygienic criteria of toxic properties of the identified elements and/or their compounds [12].

The purpose of this article is to assess the air pollution level in vicinity of coal-fired and oil-fired boiler-house plants in the territory of Tomsk Oblast. The main objectives of the present study are (a) to determine the content of trace elements in solid airborne particles deposited in snow; (b) to reveal the most hazardous elements with the maximum concentrations in solid airborne particles deposited in snow depending on used fuel type in the boiler-house plants; (c) to assess the non-carcinogenic risk of population health from chronic inhalation of trace elements contained in solid airborne particles.

2. METHODS

Snow sampling was performed at the end of February, 2016 to study the composition of solid particles deposited in snow cover over the winter season. In the vicinity of coal-fired boiler house the sampling points were located at the distance from 30 to 230 m from the stack, oil-fired boiler house – from 50 to 250 m from the stack along the main wind direction. Sampling and snow sample preparation were made in accordance with regulations (RD 52.04.186 № 2932-83), a number of published research works [6-9] and our research experience [10-12].

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The object of the study was a solid snow phase in the form of solid airborne particles deposited in snow. Concentration of Al, As, Cd, Se, Pb, Zn, Co, Ni, Mo, Cu, Sb, Cr, Ba, V, Mn, Sr and W was defined in 17 samples using mass-spectrometry with inductively couples plasma (ICP-MS). Hg concentration was measured in the samples by atomic-absorption analysis.

In the present study to reveal the abnormal microelement concentration as compared to background one, the concentration coefficient of trace elements (K_k) is determined using the formula [6-7]:

$$K_{k,i} = C_i / C_f \quad (1)$$

C_i is the trace element concentration in the considered snow sample (mg/kg); C_f is the background trace element concentration (mg/kg). The background area is 'Background' Observatory (Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences). If the snow is contaminated with more than one heavy metal, the contamination level is evaluated based on the total contamination factor Z_d, which is equal to:

$$Z_c = \sum K_{k,i} - (n-1) \quad (2)$$

n is the number of heavy metals, having $K_{k,i} \geq 1.5$ [6-7].

Based on the Z_c value, the degree (level) of snow contamination using the total contamination factor is as follows: < 32 – allowable; 32–64 – moderately hazardous, 64–128 – hazardous; 128–256 – highly hazardous and > 256 – extremely hazardous [6-7].

Sanitary-hygienic assessment of the element content in solid air particles in the areas located close to boiler is performed by calculation of hazard quotient (HQ_i) and non-carcinogenic human health risk assessment [13-14]. HQ_i is calculated on the basis of data on the element composition of solid airborne particles deposited in snow.

Non-carcinogenic human health risk assessment from chronic inhalation of trace elements to the body is based on the hazard quotient (HQ_i) calculations:

$$HQ_i = C_{iatm} \Big/ R_f C_i \quad (3)$$

$R_f C_i$ is reference concentration of the i-th element in the air, according to EPA's IRIS, HEAST EPA.

To identify priority organs and systems which are mostly affected by combined influence of several elements, total hazard index (HI) is calculated for each organ or system:

$$HI = \sum HQ_i \quad (4)$$

In cases when a metal affects the functioning of several systems or organs, its HQ was taken for each system separately.

Besides, the data on element air concentrations are used in calculations [10]. This data is reestablished taking into account air dust deposition rate of airborne dust and size of airborne dust particles.

3. RESULTS AND DISCUSSION

The analysis of concentration coefficients has shown that in the samples taken near the coal-fired boiler house there are Sb, Cd, Sr, Ba and Zn that make a group of elements with high accumulation in terms of average values of concentration coefficients (Table 1). The cumulative pollution indicator amounts 47.8 on average, which corresponds to the environmental conditions of moderately hazardous contamination level and moderately hazardous for human health. The content of Ni, Sb and V in samples of solid snow samples taken near the oil-fired boiler house is uneven. In terms of average values of concentration coefficients, Ni, Sb and V form a group of elements with high accumulation in solid snow phase. Sr, Mo, Cd and Ba accumulate less intensively in the samples of solid snow phase, whereas the content of other elements (Cr, Mn, Co, Cu, Zn, As, Se, W, Pb and Hg) is close to the background values.

Table 1 Geochemical characteristics of the solid phase of snow in the vicinity of coal-fired and oil-fired boiler houses in Tomsk Oblast

Boiler house plant	Coefficient concentration of trace elements			Z_c
	≥ 1.5	1.6-5	5-25	
Coal-fired boiler house	$Se_{0,1}As_{0,3}V_{0,4}Cr_{0,5}Cu_{0,8}$ $W_{1,1}Mn_{1,5}$	$Hg_{1,9}Pb_{2,4}Ba_3Co_{3,1}$ $Ni_{3,1}Zn_{3,2}Mo_{3,3}Sr_{4,2}$	$Cd_{7,2}Sb_{24,8}$	47.8
Oil-fired boiler house	$Se_{0,1}W_{0,1}Cu_{0,7}Cr_{1,1}Pb_{1,4}$ $As_{1,4}Co_{1,4}Hg_{1,5}Mn_{1,5}Zn_{1,5}$	$Sr_2Cd_2Mo_{2,2}Ba_{2,2}V_{4,8}$	$Sb_{7,0}Ni_{8,4}$	23.1

The most studied elements have calculated values of HQ_i much less than 0.1, which, according to the domestic and foreign recommendations [13-14], allows them to be considered as posing no risk to human health (Table 2).

Table 2 Non-carcinogenic human health risk assessment from chronic inhalation of trace elements to the body during inhalation in the vicinity of coal-fired and oil-fired boiler house plants in Tomsk Oblast

Element	Code CAS	Organs/systems	RFC, mkg/m^3	Coal-fired boiler house		Oil-fired boiler house	
				$C_{atm}\pm\delta_m$, mkg/m^3	$HQ_i\pm\delta_m$, units	$C_{atm}\pm\delta_m$, mkg/m^3	$HQ_i\pm\delta_m$, units
Al	7429-90-5	systema nervosum centrale, respiration organs	5	3.85±1.99	0.77±0.40	0.39±0.07	0.08±0.01
Mn	7439-96-5	systema nervosum centrale	0.05	0.018±0.007	0.37±0.15	0.004±0.001	0.07±0.02
Cu	7440-50-8	respiration organs, systematic effect	0.02	0.005±0.002	0.23±0.11	$8.5\cdot10^{-4}\pm10^{-4}$	0.04±0.01
Ba	7440-39-3	reproductive function	0.5	0.071±0.038	0.14±0.08	$7\cdot10^{-3}\pm10^{-3}$	0.014±0.003
Co	7440-48-4	respiration organs, systematic effect	0.02	0.001±0,001	0.07±0.04	$9.8\cdot10^{-5}\pm10^{-5}$	0.005±0.001
Pb	7439-92-1	systema nervosum centrale, progression, blood system	0.15	0.0075±0.003	0.05±0.01	$1.2\cdot10^{-3}\pm10^{-4}$	0.008±0.001
Ni	7440-02-0	respiration organs, blood system, immune system, systema nervosum centrale	0.05	0.0003±0.0001	0.005±0.002	$1.3\cdot10^{-3}\pm10^{-4}$	0.03±0.003
V	7440-62-2	respiration organs	0.07	0.0006±0.0003	0.009±0.004	$1.2\cdot10^{-3}\pm10^{-4}$	0.017±0.002

C_{atm} (mkg/m^3) is the reestablished element concentration in air using the data on element composition of solid snow sediments; HQ_i is the hazard quotient of non-carcinogenic human health risk assessment from chronic inhalation of trace elements to the body.

Hazard quotient of six elements is higher than 0.05; Al, Mn, Cu, Ba, Co and Pb constitute the maximum specific share in the integral level of non-carcinogenic risk from chronic inhalation of metals in the vicinity of coal-fired boiler house, whereas in the vicinity of oil-fired boiler house are Al, Mn, Cu, Ni and V.

4. CONCLUSION

It is revealed that the potential element-indicators in solid snow phase posing a serious environmental risk in the vicinity of coal-fired boiler house are Cd, Sb, Pb, Mo, Sr, Ba, Ni, Mo, Zn and Co; in the vicinity of oil-fired boiler house are V, Ni and Sb. It is stated that near the coal-fired boiler house there is the moderately hazardous level of contamination, while in vicinity of the oil-fired boiler house there is the allowable level of contamination. The study has shown that in

vicinity of the coal-fired boiler house there are more hazardous ecological conditions as compared to the environment near the oil-fired boiler house. The revealed elements-indicators in the solid snow phase are most likely to reflect the specificity of fuel and fly ash. When burning, they are released and changed into more available forms digested by human beings and biota.

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