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Macroelement and Mineral-Phase Composition of Particulate Matter in the Impacted Area of Cement Production Plant Based on Snow Cover Study (Kemerovo Region)

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Abstract

The paper presents the assessment of the spatial distribution of the dust load, macroelement (Ca, Na, Fe, Al, Si, Mg) and mineral-phase composition of particulate matter deposited in snow cover in the impacted area of cement production plant (Topki, Kemerovo region). It was determined that the dust load exceeded the background from tens to hundreds times. The dust load was estimated from allowable to highly hazardous pollution levels. The main crystalline phases included calcite and quartz in the particulate phase of snow and emitted dust from the plant. Additionally, the particulate phase of snow contained the minerals of Portland cement clinker such as brownmillerite and hatrurite. The content of these four minerals mainly controlled the dust load. The content of Ca (10-12 times higher than background values) in the particulate phase of snow showed the anthropogenic geochemical specificity of the samples and it is comparable to the content in the emitted dust from the plant and portland cement. We identified fine particles of Ca ferrites, Fe oxides as most abundant particles in the samples, as well as trace amounts of Ca aluminate and Fe sulphide particles. The main types of particulate matter were suggested to be pit operation, transport and load handling works in the plant. The long-range transport of particulate matter was revealed in the north direction at 2 km distance from the plant. The dust load decreased with the distance from the plant. The identified crystalline phases and fine particle types can be used as tracers for cement production plant emissions.

Key words: cement plant, snow cover, macroelements, fine particles, minerals, particular matter pollution

INTRODUCTION

Evaluation of the effect of industrial enterprises on the formation of the composition of environmental components is one of the urgent tasks of environmental geochemistry. The cement industry is a powerful source of atmospheric pollution. One of the marker substances released into the environment by cement plants is dust (solid particles) [1]. Dust emitted by these plants is characterized by the high content of CaO (39.4–53.1 %) and SiO_2 (7.1–27.9 %), and 75 % of its composition is formed by the particles less than 10 μm, which are dangerous for the human respiratory tract. In some cases, high concentrations of K_2O (up to 11.2 %) and sulphur (up to 7.8 %) are observed in the dust [1]. Chronic bronchitis, bronchial asthma, oncological diseases, lung pathologies, conjunctivitis, dermatitis are diagnosed in the population of the zones affected by dust emissions; the workers suffer from silicosis [2].

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Determination of the level of dust pollution in the zones affected by cement plants and analysis of the products of their emissions in the environment are urgent problems for revealing the regularities of the atmospheric transport of the emitted dust particles, analysis of their qualitative and quantitative characteristics, and development of the measured for environmental protection. Snow cover is an ideal environmental component to study the composition of industrial emissions because it is able to accumulate pollutants from the air [3–8].

The goal of the present work was to reveal the regularities of the distribution of dust load, as well as macroelements (Ca, Na, Fe, Al, Si, Mg) and mineral phase components in the composition of dust particles deposited onto the snow cover within the zone affected by the cement plant.

OBJECTS AND METHODS OF INVESTIGATION

The cement plant in Kemerovo Region (Topki) was chosen as the object of investigation. It is a large cement plant in Russia manufacturing 3.7 mln t of cement per year. The plant is situated at a distance of 5 km from the residential area of Topki and serves as the major source of the pollution with dust releasing substantial amount of inorganic dust. According to the data of State Reports on the state and conservation of the environment in the Kemerovo Region, a decrease in the emissions of pollutants was detected from 2013 to 2016 in the atmospheric air of the city of Topki, Topkinsky district (2013 – 9.6 thousand t and 216 kg/person, 2014 – 9.5 thousand t and 215 kg/person, 2015 – 8.8 thousand t and 199 kg/person; 2016 – 5.4 thousand t and 124 kg/person). The city of Topki is related to the group of cities with relatively high parameters of morbidity and mortality, and the high level of lung cancer. In this group, the largest fraction is that of the male population at the age of 30 years and older [9]. Analysis of the dynamics of the rate of lung cancer in the population during the years since 1990 till 2009 showed that the Topkinsky district related to unfavourable territories with a trend to decrease or stabilize the rate of lung cancer among males [10]. During the years 2000–2009, statistically significant excess over the average rate of lung cancer in males for the Kemerovo Region was detected.

The snow cover samples were collected in February 2016 in the zone affected by the cement plant in Topki (Fig. 1). Sampling sites were located using the vector system taking into account the prevailing wind direction (south-western), the height of chimney-stalks and the relief of the territory.

Sampling routes stretched to the north, north-western and south-eastern directions at a distance of 0.5 to 2.5 km from the chimney-stalks. The samples collected at a distance shorter than 1 km were taken within the boundaries of the sanitary protective zone (SPZ). Sampling was also carried out in the region of the open pit where limestone and clay for the plant were mined, and in the residential area of Topki (at a distance of 5 km from the plant). A territory at a distance of 53 km from Topki was chosen as the background area. The number of snow cover samples was 15 in the zone affected by the plant and 10 in the background region.

Samples were taken from the snow pit through the whole thickness of the snow cover except a 5 cm thick layer just above the soil to avoid sample contamination with soil particles. The samples were melted at the room temperature, then the melted snow water was filtered to isolate dust particles deposited onto the snow cover. After filtration, the solid residue was sieved (through a sieve with the mesh diameter 1 mm) and weighted.

Calculation of the dust load P_d was carried out using equation [3]: $P_d = P_0/(S \cdot t)$, where P_0 is the mass of the solid residue from snow, mg; S is the square of snow pit, m^2; t is the time from the time representing the stable snow cover formation duration up to sampling day, days. With the help of the accepted grades of dust load [3] with supplements [4], the degree of pollution and the extent of the ecological danger were determined for the territories: less than 250 mg/(m$^2 \cdot$ day) – low, not dangerous; 251–450 – medium, moderately dangerous; 451–850 – high, dangerous; above 851 – very high, extremely dangerous. For the comparative analysis of the composition of the solid residue from snow, dust samples from the electric filters of the rotating furnaces of the plant were collected and analyzed, as well as the samples of portland cement manufactured at the plant.

Investigation of the composition of samples was carried out in the laboratories of the International Innovation Research and Educational Centre «Uranium Geology» at the TPU (Tomsk). Instrumental neutron activation analysis (INAA) was used to analyse the content of Ca, Na and Fe in the samples. The content of Al, Si and Mg in the samples of the solid deposit from snow was determined by means of mass spectrometry with inductively coupled plasma (ICP-MS) at the ac-

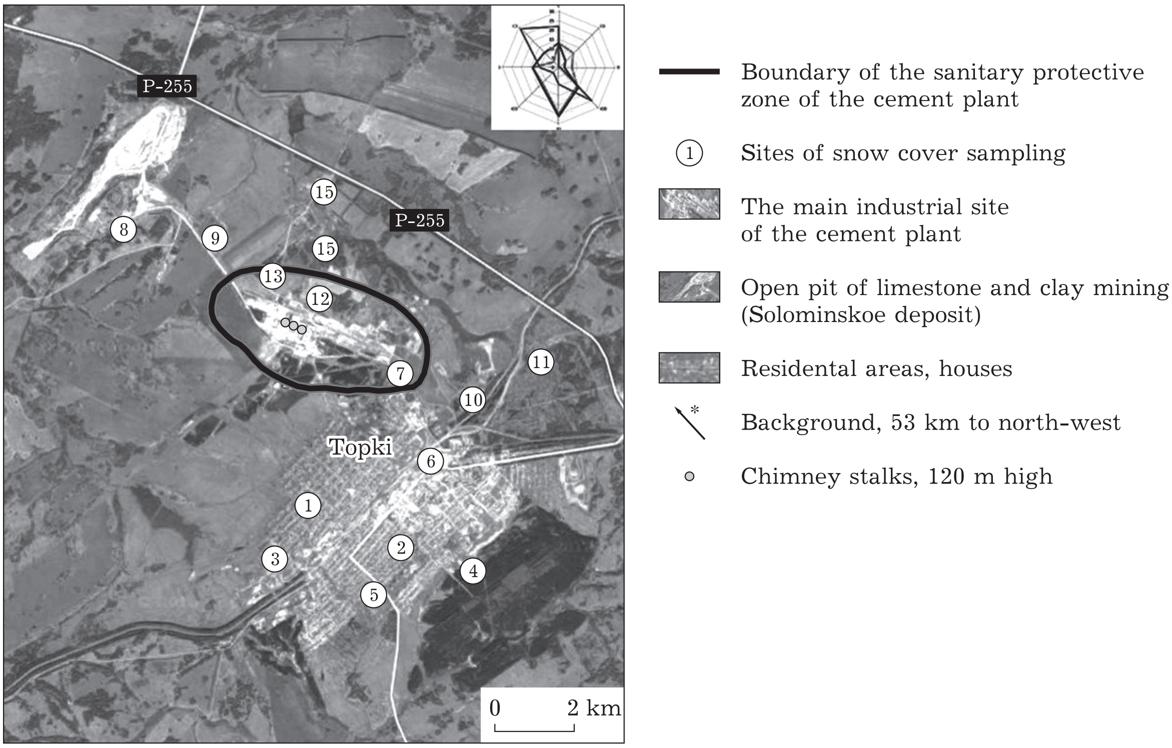


Fig. 1. Map of snow cover sampling in the zone affected by the cement plant at the territory of Topki (https://www. google.ru/ maps/ with supplements made by the authors; samples No. 1–6 – residential area of Topki, samples No. 7, 12, 13 – sanitary protective zone of the plant; samples No. 7, 10, 11 – south-eastern zone; samples No. 9, 12–15 – north-western zone; samples No. 13–15 – northern zone; sample No. 8 – the region of the open pit where limestone and clay are mined).

credited laboratory of the Chemical Analytical Centre Plasma (Tomsk).

Investigation of the mineral phase composition of the samples was carried out with the help of powder X-ray diffractometry (PXD) with a BrukerPhaser D2 diffractometer (Germany). Semi-quantitative mineralogical analysis of X-ray diffraction patterns was carried out using the Diffrac.Eva. V3.2 software. The morphology (size, shape) and semi-quantitative elemental composition of separate fine particles in the samples were studied using a scanning electron microscope S-3400N Hitachi (Japan) with the energy-dispersive attachment for X-ray spectral analysis Bruker XFlash 4010 (Germany).

The maps of the spatial distribution of dust load and calcium in the solid residue of snow at the territory under investigation were drawn with the help of Surfer 11 software (Natural Neighbor method).

RESULTS AND DISCUSSION

Dust load

The background dust load is 9.2 mg/($m^2 \cdot$ day), which is comparable with the background for the non-chernozem zone of the European part of Russia (10 mg/($m^2 \cdot$ day)) [3] and for the West Siberian region (7 mg/($m^2 \cdot$ day)) [8].

The value of dust load on the residential part of Topki corresponds to the low degree of pollution according to gradation [3, 4] and exceeds the background value by a factor of 3 (Table 1).

In the zone affected by the cement plant, the value of dust load varies from 142 to 4616, the average value being 1243 mg/($m^2 \cdot$ day). Within the SPZ (0.5 and 0.9 km from chimney-stalks), a very high degree of pollution is formed, and the ecological situation is extremely dangerous: an excess over the background by a factor of 50 to 500 is revealed. In the northern and north-western zones from the plant, a very high degree of pollution is formed, with the extremely dangerous ecological situation according to gradation [3, 4] (see Table 1). The average value of the dust load in these zones exceeds the background level by a factor of more than 100.

In the south-eastern zone, a high degree of pollution and dangerous ecological situation were revealed. The average dust load in this zone exceeds the background level by a factor of 65.

Analysis of the spatial distribution of dust load shows that dust particles spread in the

TABLE 1

Dust load on snow cover in the zone affected by the cement plant

Zone	Number of samples	Average P_d, mg/($m^2 \cdot$ day)	Degree of pollution, level of ecological danger [3, 4]	Min.	Max.
				mg/($m^2 \cdot$ day)	
Residential (Topki)	6	27.6	Low, no dangerous	12.4	75.0
Sanitary protective	3	2124	Very high, extremely dangerous	457.0	4616
Northern	4	885.4	The same	174.2	1244
North-western	5	1243	»	141.7	4616
South-eastern	3	600.1	High, dangerous	207.2	1078
Open pit	1	273.9	Medium, moderately dangerous	N. D.	N. D.

Notes. 1. Background– 9 mg/($m^2 \cdot$ day); 2. N. D. – no data

northern and north-western direction from the plant (Fig. 2, *a*). A trend for the substantial decrease in dust load with an increase in the distance from the source towards the north was revealed: from 4616 (0.5 km from the chimney-stalks) to 174 mg/($m^2 \cdot$ day) (2.3 km from the chimney-stalks).

The highest values of dust load were revealed within the boundaries of the SPZ and in the northern zone affected by the plant. Dust enters the environment mainly during loading-unloading operations according to the data on the maximum permissible emission level, and also with the emissions from chimney-stalks. Near the loading platform (within the SPZ, at a distance of 0.5 km from the chimney-stalks) where cement transportation in the bunkers of cement mills and open loading of portland cement into railway and motor transport are carried out, dust load exceeds the background by a factor of more than 500. It was also demonstrated in [5, 7] that the deposition of suspended dust matter on the snow cover is maximal at a distance of 0.2 to 0.7 km from the chimney-stalks of cement plants. We do not exclude the formation of additional dust pollution in the northern zone affected by the [plant

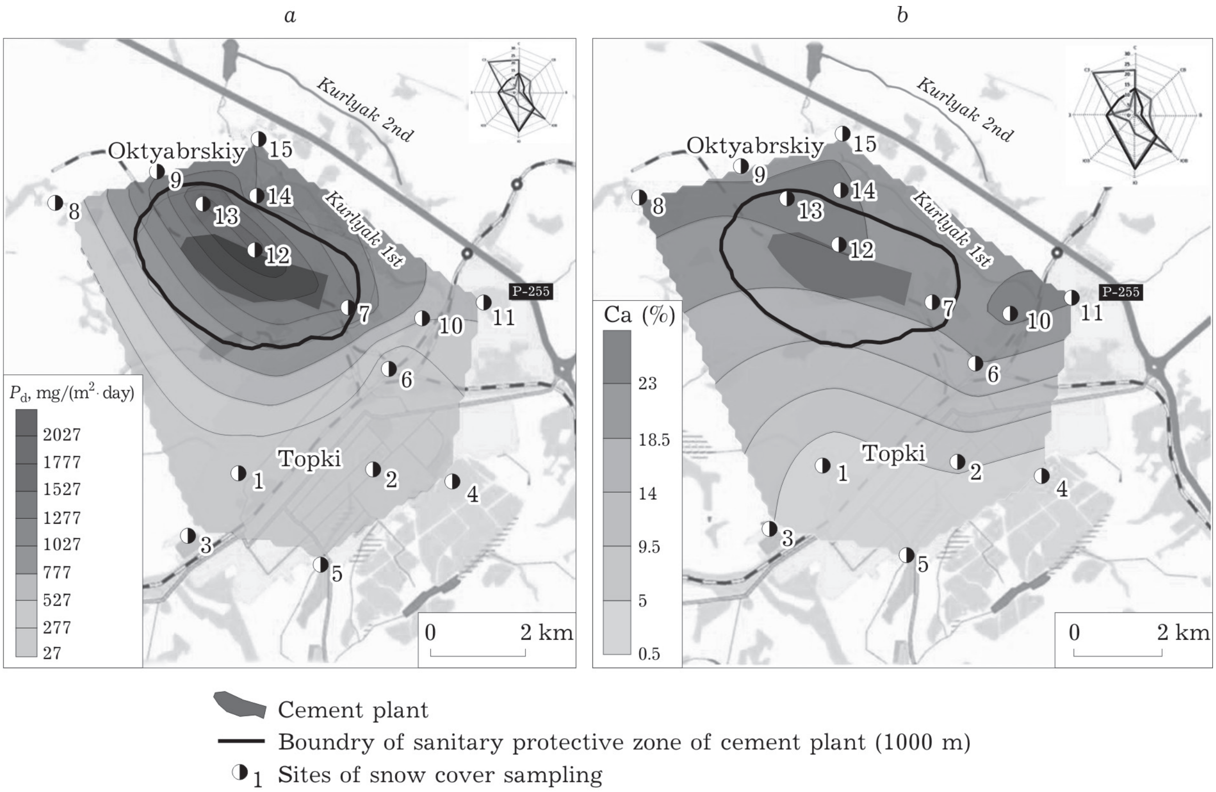


Fig. 2. Map of the spatial distribution of dust load (*a*) and calcium (*b*) in the zone affected by the cement plant, according to the data of snow survey

due to the transport of dust particles from barrow excavation at the open pit.

The medium degree of pollution and moderately dangerous ecological situation are formed near the open pit (the background is exceeded by a factor of 30). The contribution into dust load is made by the open mining of limestone and clay by means of drilling and blasting operations, as well as the transportation of the mined raw material into the technological works using dump trucks (including BELAZ) and other means of transport.

Macroelement composition

The macroelement composition of the solid residue from snow is mainly represented by Ca: its content in the samples from the zone affected by the cement plant is 10 times higher than the background values, in the samples from the region of the open pit it is 12 times higher, and at the territory of Topki it is 3 times higher than the background value (Tables 2 and 3). The content of other macroelements in the samples does not exceed the background level (see Table 2). Calcium content in the samples is much higher than Si, Al, Fe, Na, Mg content.

With an increase in the distance from chimney stalks in the northern direction, insignificant variations of Ca and Na content are detected in the samples. This may be connected with the transfer of the emitted solid particles and the particles of raw materials and products over long distances in the prevailing wind direction. An interconnection between increased Ca content in the samples and the high values of dust load was revealed in the northern zone affected by the cement plant (see Fig. 2).

The concentration of Ca and Na in the solid residue from snow in the zone affected by the cement plant is comparable with the concentration of these elements in the dust from electric filters, which probably points to the technogenic source of elements in the snow cover (see Table 2). The content of Al and Si in the solid residue from snow demonstrates a trend to increase with an increase in the distance from the chimney stalks and reaches the maximal value at a distance of 2.3 km where a rural settlement is situated.

The particles of portland cement, the product manufactured at the plant, may also enter the atmospheric air during loading-unloading operations. These particles are characterized by the increased content of the elements under investiga-

TABLE 2

Average content of macroelements in the solid residue from snow in the zone affected by the cement plant and in dust from the electric filters of rotating furnace, %

Samples	Ca	Na	Fe	Al	Si	Mg
Zone:						
Residential (Topki)	7.3	0.6	2.7	3.5	8.6	0.7
Sanitary protective	23.3	0.1	1.7	1.6	5.1	0.6
Northern	23.7	0.2	1.9	1.8	5.8	0.6
North-western	23.2	0.1	1.8	1.8	5.7	0.6
South-eastern	22.8	0.1	2.2	2.6	8.1	0.8
Open pit	25.6	0.1	0.8	1.2	3.9	0.5
Background	2.2	0.9	2.6	6.3	24.3	0.9
Dust from electric filters	20.6	0.3	1.9	N. D.	N. D.	N. D.
Portland cement	31.7	0.2	2.6	N. D.	N. D.	N. D.

Notes. 1. Here and in Table 3: for Ca, Na, Fe INAA data are presented; Al, Si, Mg – ICP-MS data. 2. N. D. – no data.

TABLE 3

Macroelemental composition of the solid residue in snow from the northern zone affected by the cement plant, %

Distance from chimney stalks, km	Ca	Na	Fe	Al	Si	Mg
0.5	24.1	0.09	1.7	1.3	4.7	0.6
0.9	25.3	0.1	1.3	1.5	5.0	0.6
1.2	23.9	0.1	1.9	1.7	6.1	0.6
2.3	21.9	0.2	1.5	2.3	6.4	0.5
Background	2.2	0.9	2.6	6.3	24.3	0.9

Note. For designations, see Table 2.

tion (see Table 2), as well as CaO, SiO_2, Al_2O_3, Fe_2O_3, Na_2O + K_2O and other admixtures [11]. The source of Ca in the production of cement is limestone ($CaCO_3$), Fe may enter the environment in the case if iron-containing additives hematite (Fe_2O_3) and ferrous-ferric oxide (Fe_3O_4) are added into the raw mixture [11].

Mineral phase composition

Crystalline and amorphous phases were revealed by means of PXD in the samples of the solid residue from snow in the northern zone affected by the plant, in the region of the open pit, and in dust from electric filters (Table 4). The fraction of the crystalline phase in the samples of the solid residue from snow is estimated as 82.6 to 86.2 %, while the fraction of the amorphous phase is 13.8 to 17.2 %. The content of crystalline phases does not change substantially with an increase in the distance from chimney stalks in the northern direction at a distance of 0.5, 0.9, 1.2 and 2.3 km, while the content of the amorphous phase slightly increases.

It is highly probable that the content of crystalline and amorphous phases in the samples of the solid residue from snow is connected with the propagation and deposition of the emissions from the cement plant on snow. The samples of the solid residue are strongly enriched with calcite ($CaCO_3$), they also contain a lower fraction of quartz (SiO_2), albite ($Na[AlSi_3O_8]$) and muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$) (see Table 4).

In the samples within the boundaries of the SPZ, near the loading ground, at a distance of 0.9 km from the chimney stalks, the mineral of cement clinker brownmillerite ($Ca_2(Al,Fe^{3+})_2O_5$) was revealed, and outside the SPZ at a distance of 1.2 and 2.3 km the minerals detected in the samples were brownmillerite and hatrurite (Ca_3SiO_5). Comparative analysis of the value of dust load and the content of crystalline phases in the solid residue from snow shows that the largest contribution into the dust load in the northern zone is made by calcite, quartz, as well as brownmillerite and harturite (see Table 4).

Calcite and quartz are the rock-forming minerals of limestone, which is the major component of the raw mixture for the production of portland cement clinker. These components may enter the atmospheric air during limestone and clay mining from the open pit, transportation and unloading of the raw material at the grounds of the plant; and then they may be transferred over different distances and get deposited onto the snow cover. The samples of the solid residue from snow in the region of the open pit contain about 95 % calcite and 5.4 % quartz (see Table 4).

Some calcium compounds (carbonates, silicates, aluminates and alumoferrites) are formed during clinker annealing at the cement plant not only in the form of minerals with the crystal structure

TABLE 4

Crystalline and amorphous phase content in the samples of the solid residue from snow in the northern zone affected by the cement plant, and dust from electric filters of rotating furnace (according to PXD data), %

Zones	Crystal phase	Calcite ($CaCO_3$)	Quartz (SiO_2)	Brownmillerite ($Ca_2(Al,Fe^{3+})_2O_5$)	Hatrurite (Ca_3SiO_5)	Microcline $K[AlSi_3O_8]$	Albite ($Na[AlSi_3O_8]$)	Muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$)	Sylvite (KCl)	Portlandite ($Ca(OH)_2$)	Amorphous phase	P_d
Северная:												
0.5 км	86.2	83.7	6.6	–	–	–	6.3	3.4	–	–	13.8	4 616
0.9 км	82.6	94.2	3.2	2.5	–	–	–	–	–	–	17.4	1 238
1.2 км	82.8	62.3	3.5	4.9	29.3	–	–	–	–	–	17.2	1 244
2.3 км	83.4	88.8	4.8	6.5	–	–	–	–	–	–	16,6	174.2
Open pit	83.2	94.6	5.4	–	–	–	–	–	–	–	16.8	273.9
Dust from electric filters	79.8	68.4	14.4	–	–	7	7.7	–	1.1	1.3	20.2	-

Notes. 1. P_d – dust load, mg/($m^2 \cdot$ day). 2. Dash means that the phases were not detected in samples.

but also are included into the vitrified phase [11], correspondingly, they may enter the atmospheric air with the emissions from the cement plant [1]. PXD investigation of the dust captured by the electric filters of the rotating furnace showed that this dust is enriched with calcite (68.4 %) and quartz (14.4 %), and contains small doses of sylvite (KCl), microcline ($K[AlSi_3O_8]$), albite ($Na[AlSi_3O_8]$), the product of hydration of clinker and cement – portlandite ($Ca(OH)_2$) (see Table 4). According to the standards of the maximum permissible emission level, the parameters under control at the plant under investigation are inorganic dust below 20 % SiO_2 and 70–20 % SiO_2.

The content of SiO_2 in cement may reach 25 % [11]. Brownmillerite and hatrurite are the minerals of portland cement clinker affecting the rate of cement solidification, porosity and durability [11]. Brownmillerite content of portland cement is 2–15 %, while hatrurite content is 40–65 %. The possibility of the release of the above-mentioned minerals into the atmospheric air and then on the snow cover during loading and transportation of the products cannot be excluded.

We suppose that the vitreous phase formed during clinker burning [11] may form the amorphous phase in dust from electric filters (see Table 4), which may enter atmospheric air and then be deposited onto the snow cover.

Fine particles containing macrocomponents

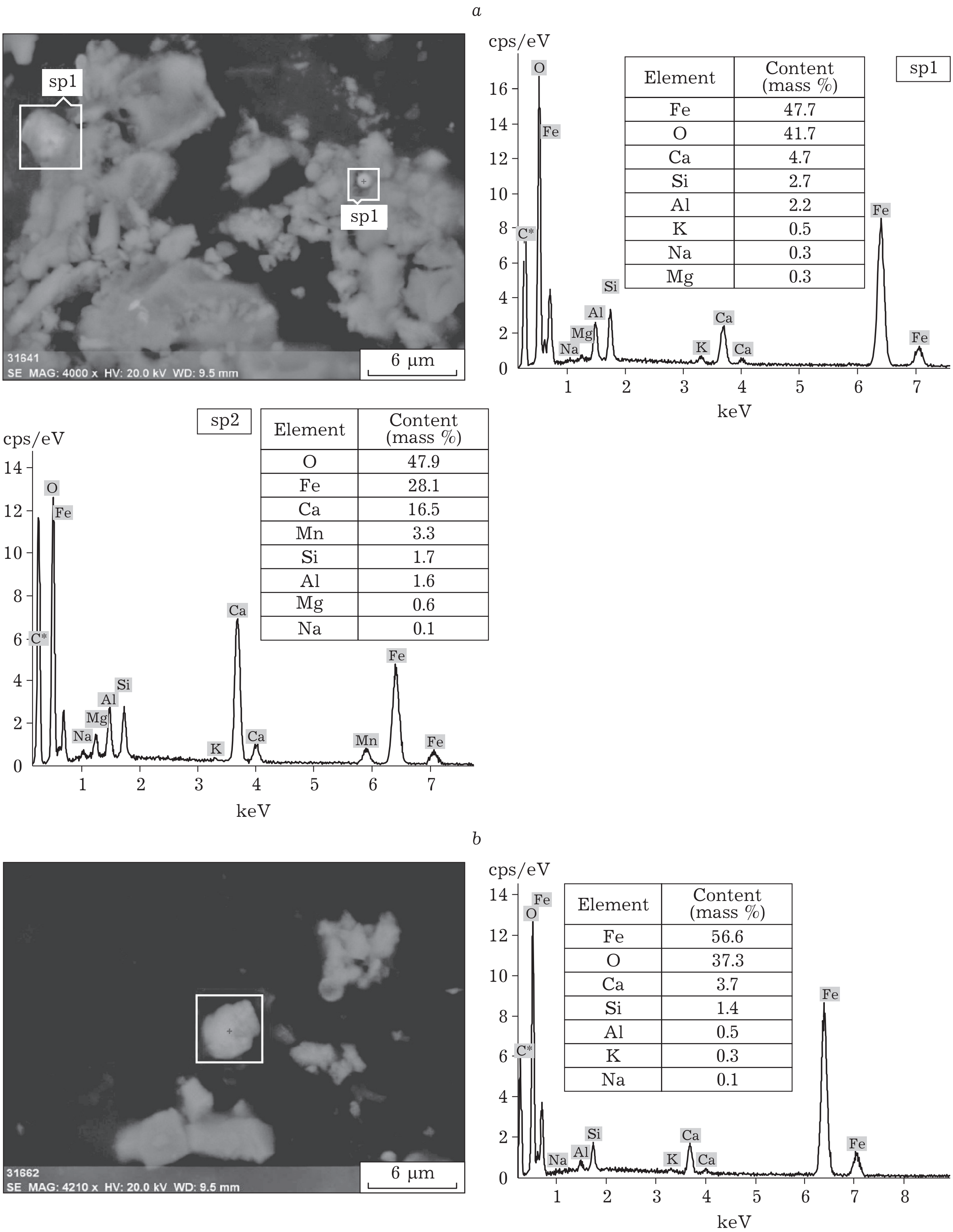
Results of the studies of the solid residue from snow by means of scanning electron microscopy showed that the examined 30 fine particles containing macroelements may be divided into seven groups (Fig. 3, Table 5): 1) Ca-Fe-enriched particles close in composition to calcium ferrites; 2) Ca-Fe-enriched spherules; 3) particles with calcium

TABLE 5

Characteristics and elemental composition of fine particles containing macroelements, in the solid residue from snow in the northern zone affected by the plant, and in dust from electric filters

Group of particles	Size, μm (min.–max.)	Shape	Content, %	Average content of macroelements, mass %								Admixtures, mass %
				Ca	Si	Al	Na	Fe	Mg	K	O	
				Northern zone affected by plant								
Ca-Fe-enriched	3.5–22.6	Rounded, prismatic, irregular, elongated, angular	32	19.3	2.9	5.0	0.3	32.2	0.7	0.4	38.7	S (0.2); Ti (0.4); Zn (1.4); Mn (2.5)
The same, spherules,	0.9–4	Spherical	8	20.5	3.0	2.2	0.3	27.8	0.9	0.2	43.0	Ti (0.5); Pb (0.6)
Particles with Ca oxides	3.5–6.3	Irregular, prismatic, tabular	8	38.7	1.6	3.2	–	0.8	0.5	0.3	51.8	Cr (1.6); Ti (2.4); Pb (4.0)
Ca-Al-Si-enriched particles	1.1–45.8	Elongated, rounded	12	12.1	16.3	8.5	–	6.0	1.4	1.7	52.4	Ti (0.7); Zr (5.5)
Particles with Fe oxides	2.0–20.0	Irregular, rounded, elongated, ooval	20	2.5	1.3	1.1	0.1	66.8	0.2	0.3	27.4	Ti (0.5); Zn (1.5); Mn (1.7)
The same, with sulphides	11.6	cubic	4	5.0	1.1	0.7	–	39.2	–	–	13.0	S (41)
Ca-Pb-enriched	0.4–6.3	Irregular spherical	16	18.9	6.3	2.6	0.6	1.5	0.3	3.1	38.0	Zr (0.1); Ti (2.3); Cr (7.9); Pb (27.1)
				Dust from electric filters								
Ca-Fe-enriched	2.3–3.7	Rounded prismatic	40	4.7	2.0	2.0	0.2	57.7	0.3	0.6	31.4	Zn (2.3); Ti (0.4); S (0.2)
The same, spherules	3.2	Spherical	20	3.7	1.9	0.7	0.1	55.2	0.1	0.4	37.8	S (0.1)
Particles with Ca oxides	6.8	Prismatic	20	39.1	0.7	0.9	–	–	0.3	0.3	58.7	–
The same, with Fe oxides	6.05	Irregular	20	11.7	14.8	1.9	0.6	1.6	0.2	4.2	39.2	–

Notes. 1. Data of scanning electron microscopy are presented. 2. Dash means that the elements were not detected.



sp1

Element	Content (mass %)
Fe	47.7
O	41.7
Ca	4.7
Si	2.7
Al	2.2
K	0.5
Na	0.3
Mg	0.3

sp2

Element	Content (mass %)
O	47.9
Fe	28.1
Ca	16.5
Mn	3.3
Si	1.7
Al	1.6
Mg	0.6
Na	0.1

b

Element	Content (mass %)
Fe	56.6
O	37.3
Ca	3.7
Si	1.4
Al	0.5
K	0.3
Na	0.1

Fig. 3. Microphotographs and energy-dispersive spectra of Ca-Fe-containing fine particles according to the data of scanning electron microscopy: *a* – sample from the zone affected by cement plant; *b* – dust from electric filter.

oxides, close in composition to calcite; 4) Ca-Al-Si-enriched particles which may be calcium aluminates; 5) particles with Fe oxides; 6) particles with Fe sulphides; 7) Ca-Pb-enriched particles.

It was determined that Ca is present both in coarse particles (larger than 10 μm) and in small ones (less than 2.5 μm). If these particles were present in air, they might affect human health

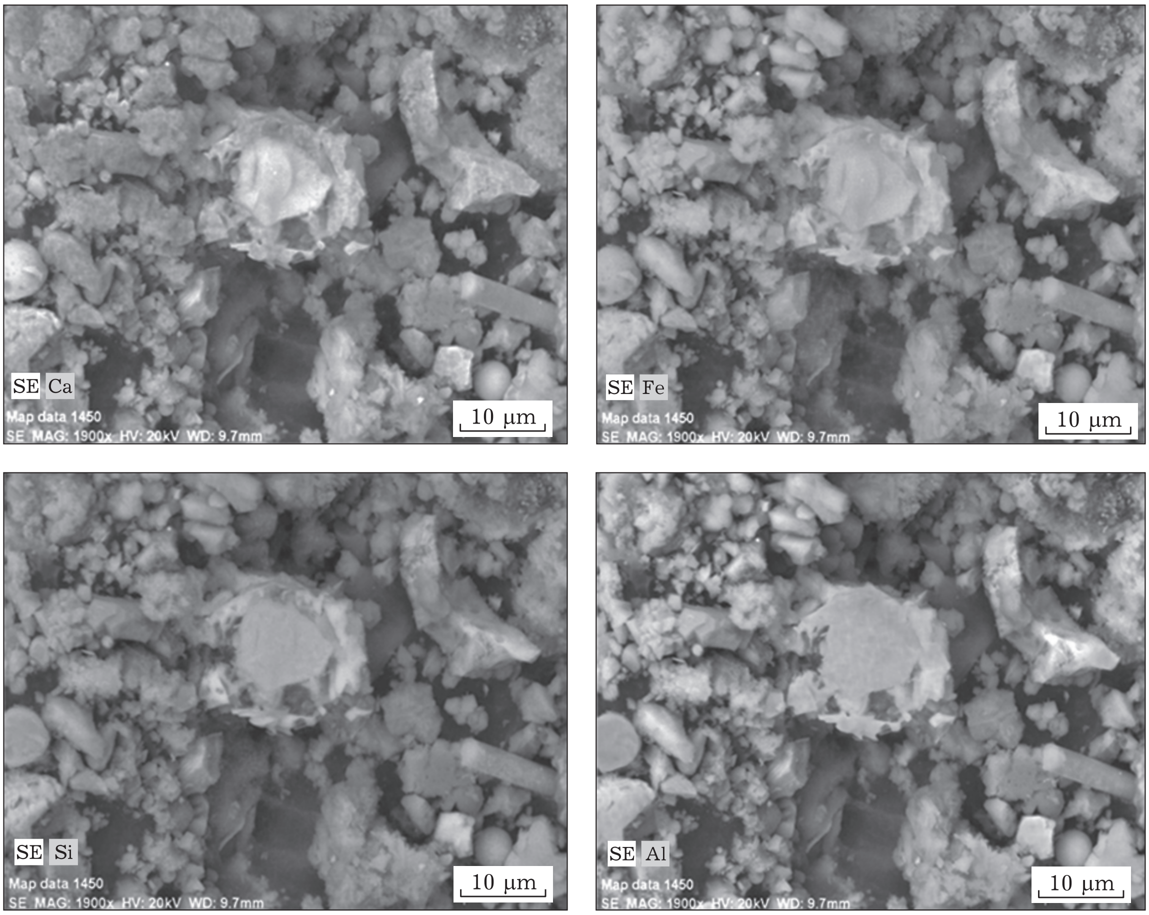


Fig. 4. Map of Ca, Fe, Si and Al distribution in the sample of the solid residue from snow in the zone affected by the cement plant (the data obtained by means of scanning electron microscopy).

causing irritation of the mucous membranes of eyes and upper air passages [2]. The revealed particles, which are close in their composition to calcium ferrites, may be deposited onto the snow cover as a result of dusting during loading works because calcium ferrites are formed and are present in portland cement [11]. The presence of Pb in the composition of Ca-Pb-enriched particles in the samples of the solid residue from snow may be due to the presence of Pb in the emissions of the cement plant according to the maximum permissible emission limit data. The majority of Pb compounds enter the atmosphere with irrevocable dust escape, and the rest part is carried out of the furnace with portland cement clinker [11].

In the samples of the solid residue from snow, prevailing particles are Ca-Fe-enriched ones (32 %) and the particles with Fe oxides (20 %) of different sizes (see Table 5).

It was revealed that these particles also comprise the basis of dust from electric filters (see Table 5, Fig. 3), therefore they may enter the atmospheric air with emissions from the plant.

CONCLUSION

As a result of the studies of the dust deposited onto the snow cover, the high dust load in the zone of the cement plant in comparison with the background and standard values was established, while the dust load in the residential areas of the city situated close to the plant was found to be low. The largest contribution into the formation of dust load is made by the crystal phases of calcite and quartz, which are the components of the raw mixture, as well as brownmillerite and hatrurite – the minerals of portland cement clinker.

Macroelement composition is mainly represented by Ca, with its content 10–12 times higher than the background values. It was established that macroelements under investigation (Ca, Na, Fe, Al, Si, Mg) are present in fine particles close in composition to calcium ferrites, oxides and aluminates, oxides and sulphides of Fe, and Ca-Pb-enriched particles.

The major mass transfer of emitted dust occurs in the northern direction from the plant at a distance slightly more than 2 km. A decrease in the dust load with an increase in the distance from the plant was evaluated. The composition of the solid residue in snow is close to the composition of dust from electric filters of the plant, which points to the presence of the components of emissions from the plant in the snow cover. The formation of the dust load, macroelement and mineral phase composition of the particles deposited on the snow cover may be connected with the propagation of emissions to a higher extent from the open pit, loading-unloading operations, transportation, and to a definite extent from organized sources equipped with a system of gas pipes and chimneys. The revealed crystal phases and solid-phase forms of macroelement occurrence may serve as the indicators of technogenic action of cement production.

Recommendations aimed at a decrease in the emission of dust from a cement plant may include the proposal to use dust and gas purifying systems the choice of which is represented in the annual handbooks of the best available technologies, a closed system of transportation, loading-unloading works, and improvement of the performance of dust-removing equipment.

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